CHANNEL GEOMETRY STREAM

METHODS FOR ESTIMATING MAGNITUDE AND FREQUENCY OF FLOODS IN MONTANA BASED ON DATA THROUGH 1983

GAGING STATIONS MAGNITUDE

BASIN CHARACTERISTICS FLOW

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 86-4027

UNGAGED SITES

CHANNEL GEOMETRY STREAM

FLOODS REGIONAL ANALYSES

GAGING STATIONS MAGNITUDE

BASIN CHARACTERISTICS FLOW

FREQUENCY UNGAGED SITES

CHANNEL GEOMETRY STREAM

FLOODS REGIONAL ANALYSES

Prepared in cooperation with the MONTANA DEPARTMENT OF HIGHWAYS; the U.S. DEPARTMENT OF TRANSPORTATION, FEDERAL HIGHWAY ADMINISTRATION; and the U.S. DEPARTMENT OF AGRICULTURE, FOREST SERVICE

MAGNITUDE

BASIN CHARACTERISTICS

U.S. DEPARTMENT OF THE INTERIOR

March 3, 1849

FREQUENCY UNGAGED SITES

CHANNEL GEOMETRY STREAM

FLOODS REGIONAL ANALYSES

METHODS FOR ESTIMATING MAGNITUDE
AND FREQUENCY OF FLOODS IN MONTANA
BASED ON DATA THROUGH 1983

by R. J. Omang, Charles Parrett, and J. A. Hull

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 86-4027

Prepared in cooperation with the MONTANA DEPARTMENT OF HIGHWAYS;
the U.S. DEPARTMENT OF TRANSPORTATION, FEDERAL HIGHWAY ADMINISTRATION;
and the U.S. DEPARTMENT OF AGRICULTURE, FOREST SERVICE

Helena, Montana
May 1986

UNITED STATES DEPARTMENT OF THE INTERIOR

DONALD PAUL HODEL, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

For more information
write to:

District Chief
U.S. Geological Survey
428 Federal Building
301 S. Park, Drawer 10076
Helena, MT 59626-0076

Copies of this report can be
purchased from:

Open-File Services Section
Western Distribution Branch
U.S. Geological Survey
Box 25425, Federal Center
Denver, CO 80225-0425

CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION FACTORS

The following factors can be used to convert inch-pound units to the International System (SI) of units.

Multiply inch-pound unit	By	To obtain SI unit
cubic foot per second	0.02832	cubic meter per second
cubic foot per second per square mile	0.01093	cubic meter per second per square kilometer
foot	0.3048	meter
inch	25.40	millimeter
mile	1.609	kilometer
square mile (mi^2)	2.590	square kilometer

Temperature in degrees Fahrenheit (°F) can be converted to degrees Celsius (°C) by the equation:

$$°C = 5/9\ (°F - 32)$$

The report is based on gaging-station data from unregulated streams having at least 10 years of streamflow record. Data through the 1983 water year were used in the analysis. The 1984 data from selected stations in southwest Montana also were included because of large flows during the spring of 1984. Included in the analysis are 375 streamflow-gaging stations in Montana, 6 in Canada, 13 in North Dakota, 3 in South Dakota, and 6 in Wyoming. Seventy-two of these stations are new additions since the study by Parrett and Omang (1981). The study included stations with drainage areas ranging from 0.04 to 587 square miles. The location and station number of gages used in the analysis are shown in figure 1. Some streamflow-gaging stations with 10 or more years of record were excluded from the analysis because the data were considered to be inadequate or unrepresentative of the region.

This report was prepared in cooperation with the Montana Department of Highways; the U.S Department of Transportation, Federal Highway Administration; and the U.S. Department of Agriculture, Forest Service. The streamflow-gaging stations used in this study were funded by the U.S. Geological Survey and various other Federal, State, and local agencies.

GENERAL HYDROLOGIC CONDITIONS IN MONTANA

Montana, the fourth largest State in the United States, has widely varying geographic and climatic conditions. The western one-half is generally mountainous and forested with large intermontane valleys. The eastern one-half is generally flat or rolling prairie with deeply incised larger streams.

The Rocky Mountains generally trend northward through the western one-third of the State, forming the Continental Divide. The northern parts of the divide are particularly steep and rugged. Smaller mountain ranges east and west of the divide also are prominent geographic features, and, in some instances, are as steep and rugged as the mountains along the divide.

The climate of the State is affected largely by the topography. Thus, in the western mountainous region, most precipitation occurs as snow produced by moist air masses originating in the Pacific Ocean. Peak flows in mountain streams can result from either spring snowmelt or spring snowmelt combined with rain. Along the east slope of the Continental Divide, severe flooding has resulted from rains produced by humid air masses originating in the Gulf of Mexico. Mountains along the west slope of the divide generally are protected from storms moving northward along the east slope. However, intense rainstorms sometimes cross the divide and can cause severe flooding along the west slope (Boner and Stermitz, 1967, p. B16-B44).

In the eastern plains region, precipitation is more variable, more intense, and generally less, on an annual basis, than in the mountains. Flows in the plains streams also are more variable than in the mountain streams and results from either snowmelt or rainfall. In some areas of the eastern plains, extreme flood peaks commonly are caused by intense summer thunderstorms. Although the entire eastern one-half of the State is probably susceptible to intense storms, streamflow records indicate that severe floods caused by thunderstorms occur in an area bounded approximately by the Missouri River on the north and the Yellowstone River on the south.

Because of the diverse topography and climate, streamflow varies greatly from the mountains to the plains. These conditions cannot be wholly defined or explained by numerical variables. It is, therefore, not possible to develop one set of equations for estimating streamflow throughout the State. Eight different sets of equations were found necessary, one set for each region of hydrologic similarity. The boundaries of the regions conform generally to different physiographic areas and are illustrated in figure 1.

The West Region (fig. 1) includes the mountainous area west of the Continental Divide where annual precipitation ranges from about 12 to 120 inches and runoff generally results from snowmelt. The Northwest Region includes the northern part of the Continental Divide where severe floods are produced by intense rainfall from air masses originating in the Gulf of Mexico. Annual precipitation ranges from about 14 to 120 inches. The Southwest Region also is a mountainous region, but precipitation generally is less than in the West Region (annual precipitation ranges from about 10 to 60 inches), and unit flood discharges, in cubic foot per second per square mile, consequently are smaller.

The Upper Yellowstone-Central Mountain Region is a mountainous, generally forested area similar to the West Region. Annual precipitation in this region ranges from about 12 to 70 inches, but generally is more variable than in the West Region. Storms in the Upper Yellowstone-Central Mountain Region may originate from the north or south as well as from the west.

The Northwest-Foothills Region is an area of mostly rolling plains just east of the mountains of the Northwest Region. Unit flood discharges in this region tend to be larger than in similar plains areas farther east, apparently because the area is partly affected by intense rainfall that causes large floods in the Northwest Region. Annual precipitation in this region ranges from about 12 to 20 inches.

The Northeast Plains Region is predominantly flat plains land north of the Missouri River. Runoff is variable, with most smaller streams flowing only intermittently. Floods are produced by snowmelt and rainfall, with annual precipitation generally ranging from about 12 to 20 inches, except in the Lewistown area where precipitation can be as much as 40 inches.

The East-Central Plains Region also is predominantly flat plains but is the area of the State most affected by intense summer thunderstorms. Annual precipitation ranges from about 12 to 40 inches. Thus, flood discharges tend to be even more variable than in the Northeast Plains Region, with annual unit flood discharges ranging from zero or near zero to several hundred cubic feet per second per square mile of drainage area.

The Southeast Plains Region is similar in topography to both the Northeast Plains Region and the East-Central Plains Region. Flood peaks from intense thunderstorms are not as prevalent in the Southeast Plains Region as in the East-Central Plains Region. Annual precipitation (about 12 to 16 inches) generally is more variable and somewhat greater in the Southeast Plains Region than in the Northeast Plains, except near Lewistown. Unit flood discharges in the Southeast Plains Region thus tend to be larger and more variable than in the Northeast Plains, but not as large or as variable as in the East-Central Plains Region.

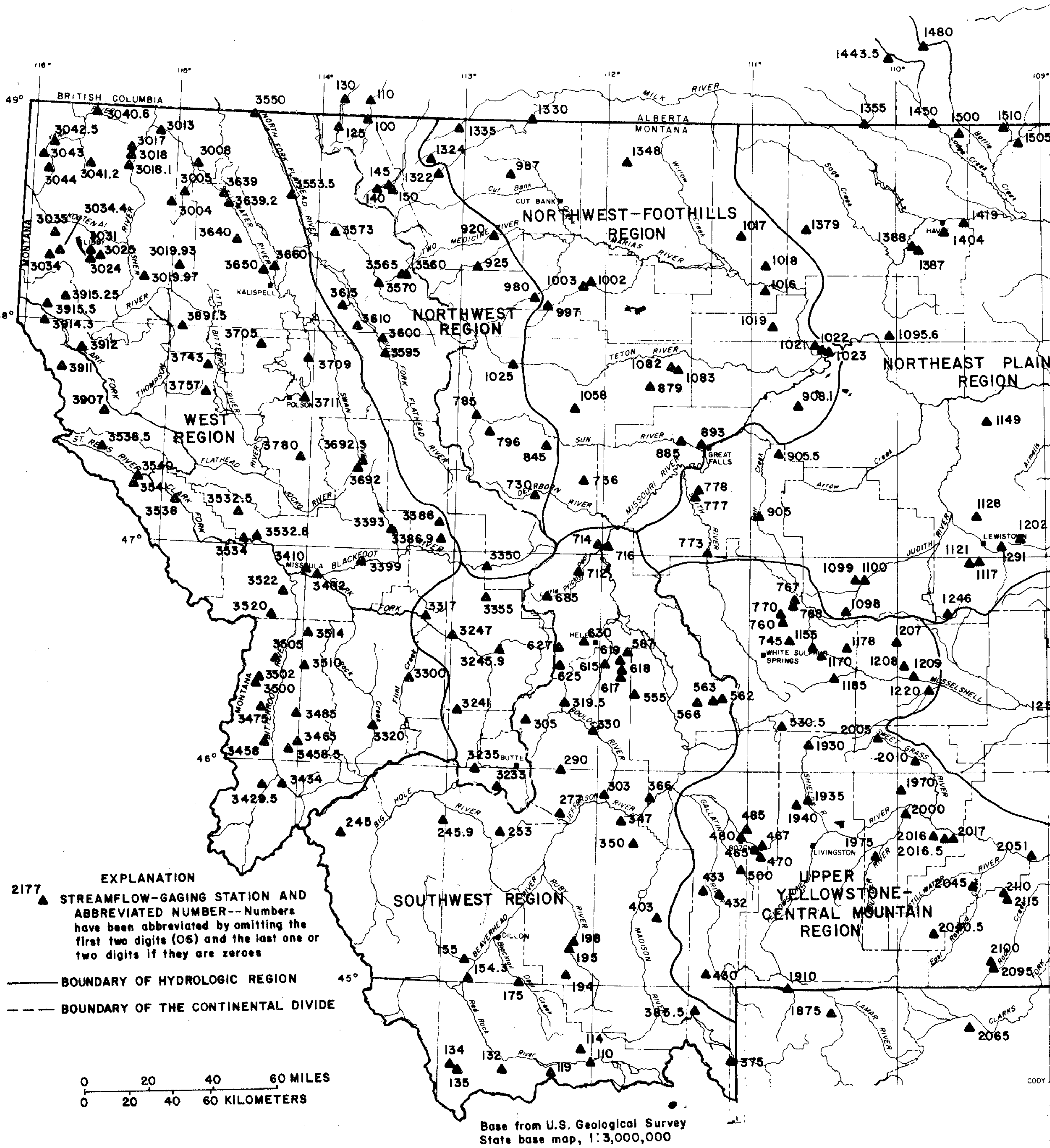
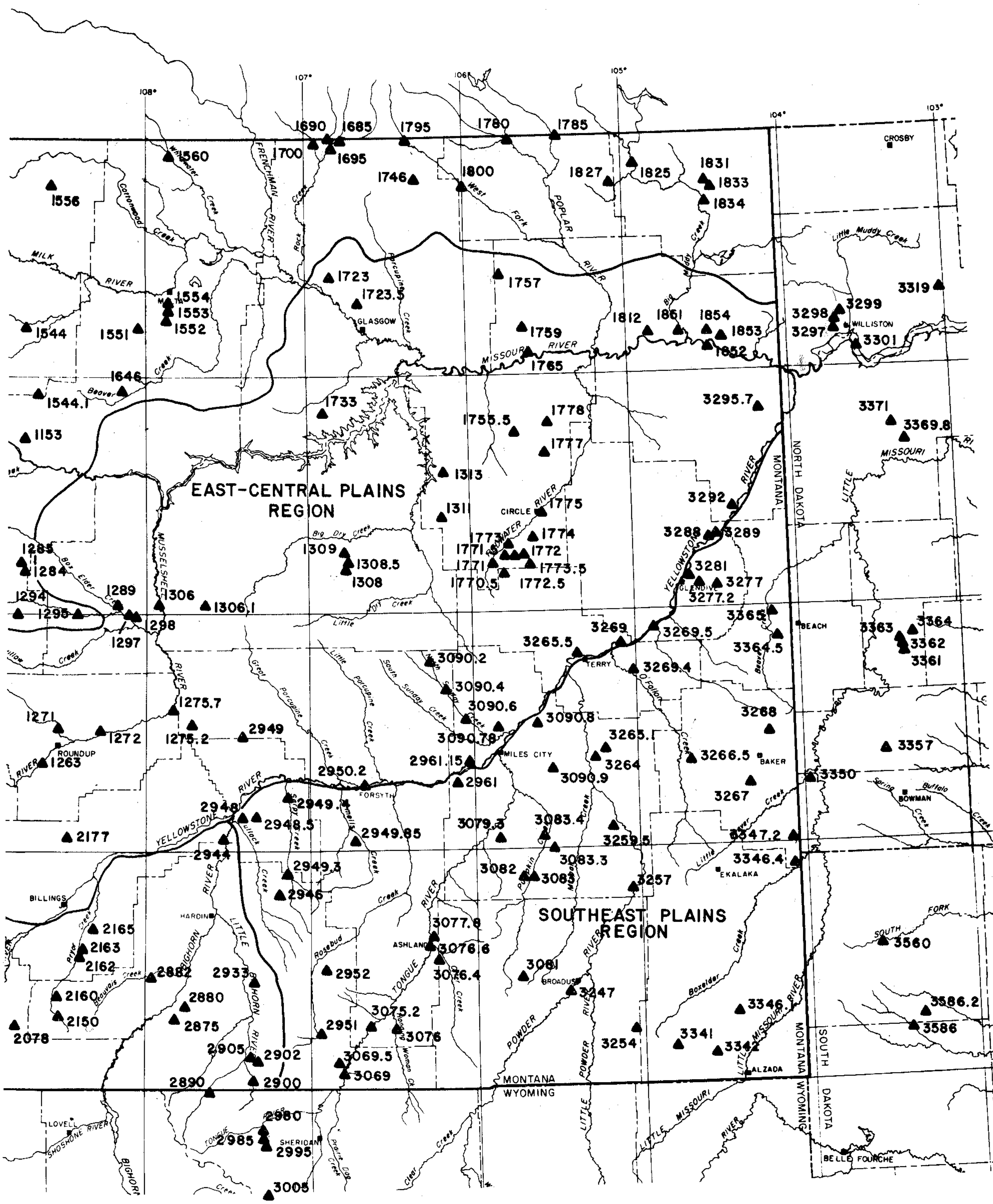


Figure 1.--Location of streamflow-gaging stations and



boundaries of hydrologic regions.

FLOOD MAGNITUDE AND FREQUENCY ANALYSIS

Flood magnitudes were determined at each streamflow-gaging station by using a log-Pearson type III probability distribution to develop a flood-frequency curve. Techniques recommended in Bulletin 17B of the U.S. Water Resources Council (1981) were used to fit the log-Pearson type III distribution to the annual peak discharges at each station. Historic adjustments to the recorded station data were used where applicable, and skew coefficients were taken from an unpublished regional map of the U.S. Soil Conservation Service. These flood-frequency curves have been improved because a longer record now is available at each station. Flood-frequency data thus derived for each station used in the analysis are listed in table 4 in the "Supplemental Data" section at the end of this report.

In describing flood frequency in this report, the term "exceedance probability" is used rather than the term "recurrence interval." Both terms are used, however, in illustrative examples. Exceedance probability is the chance in percent that a flood will exceed a given magnitude in any given year. Recurrence interval is the reciprocal of the exceedance probability times 100 and is the average time interval, in years, within which the given flood is expected to be equaled or exceeded once. For example, a 2-percent-chance flood has an exceedance probability of 2 percent and an average recurrence interval of 50 years.

Although flood estimates are sometimes required for exceedance probabilities less than 1 percent, such estimates are not very reliable. Consequently, flood magnitudes greater than the 1-percent-chance flood were not used in the analysis.

Mixed-population analysis

In the Northwest Region, flood-frequency-curve determination was complicated by a few extreme floods caused by rain within a population of smaller floods caused by snowmelt or snowmelt mixed with rain. Because the rain-caused floods are significantly larger than the more prevalent snowmelt-type floods, the log-Pearson type III distribution did not fit the data well when all floods were considered together. Accordingly, the maximum discharges at each site in the region were separated by cause -- those caused by intense rains and those caused by snowmelt or snowmelt mixed with rain. Frequency curves were then fitted to each set of maximum discharges, and the separate frequency curves were combined using procedures developed by the U.S. Army Corps of Engineers (1958). Fitting a frequency curve to the rain-caused floods was complicated by the paucity of events. Rainfall-frequency curves were prepared for all long-term rain gages in the area and were used as a guide in assigning reasonable probabilities of occurrence to the few rain-caused floods. Flood reports documenting the severity and rarity of the large rain-caused floods also were used to help assign probabilities of occurrence to rain-caused floods (Boner and Stermitz, 1967; U.S. Army Corps of Engineers, 1969 and 1973). A sample frequency curve determined by this method is shown in figure 2.

Flood-flow records in the East-Central Plains Region also were examined to determine if thunderstorm-caused floods should be separated from snowmelt-caused floods. In this instance, the two types of floods were not clearly distinct nor sufficiently independent, and separation was not warranted.

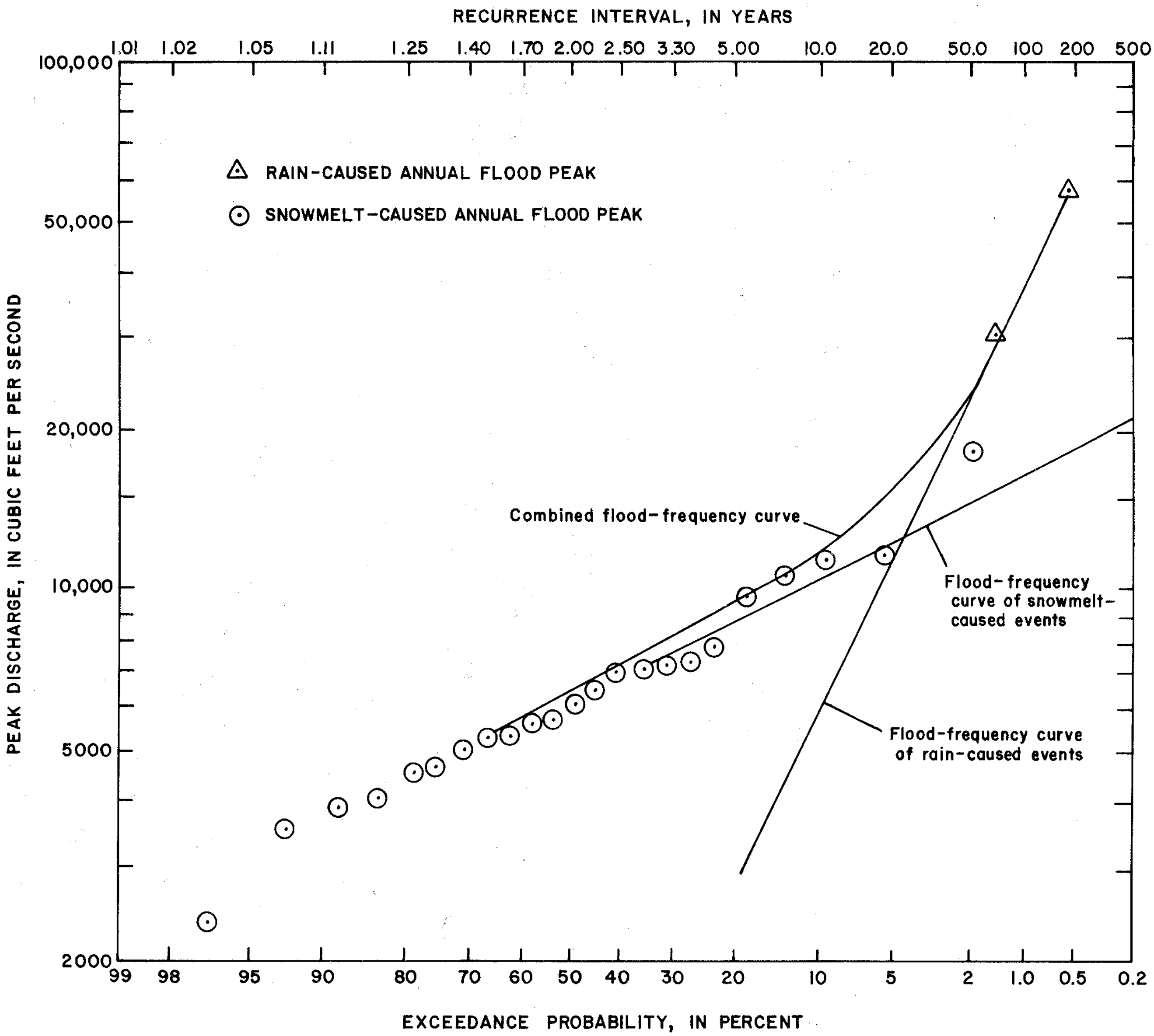


Figure 2.--Flood-frequency curve for Sun River near Augusta, Montana (station 06080000).

Regional skew

Generalized skew coefficients of logarithms of annual maximum streamflow were used in the log-Pearson type III curve-fitting procedure. For most of the State, a generalized skew map (fig. 3) prepared by S. M. Hamilton (U.S. Soil Conservation Service, Bozeman, Montana, written commun., 1982) using procedures recommended by

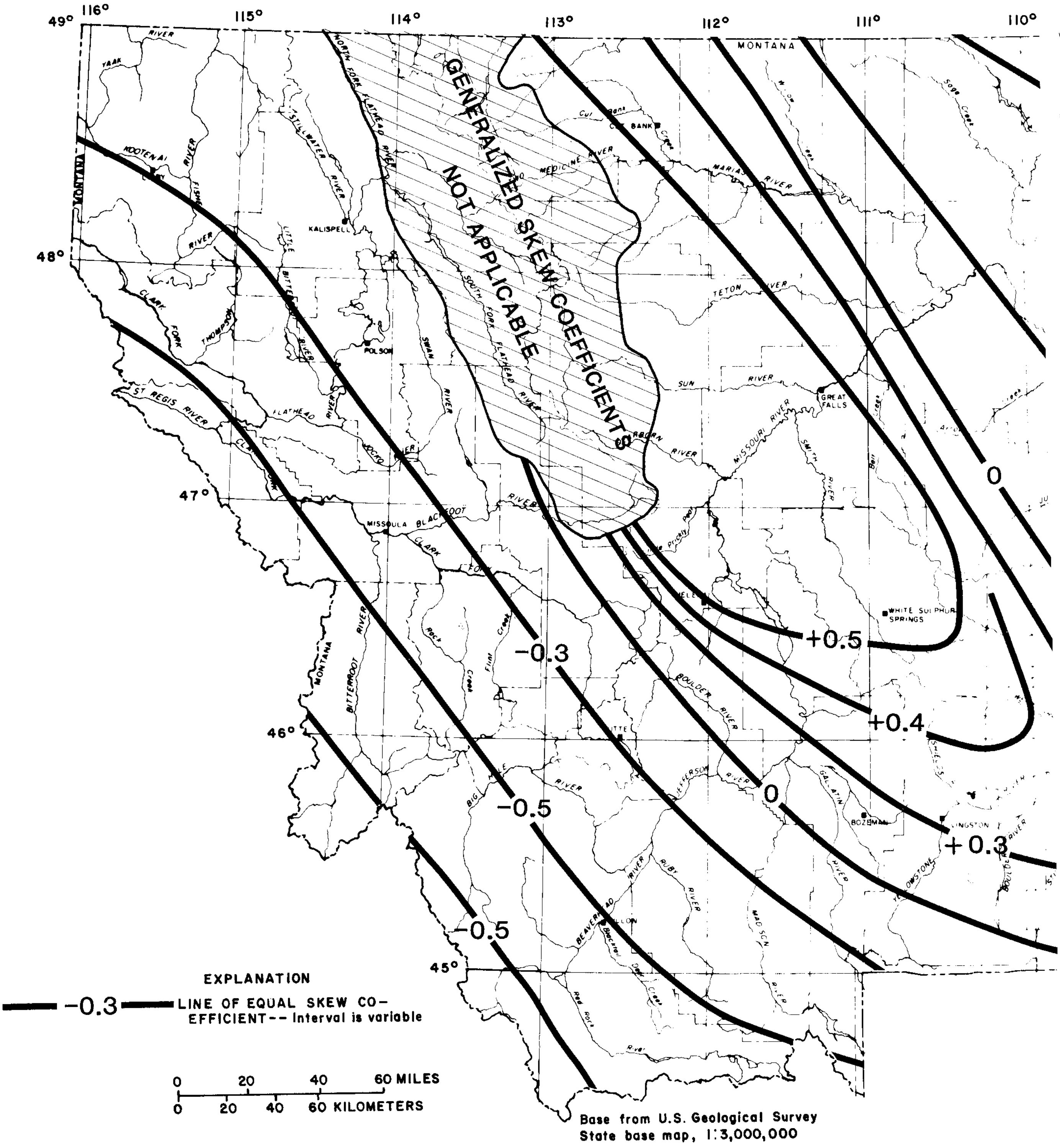
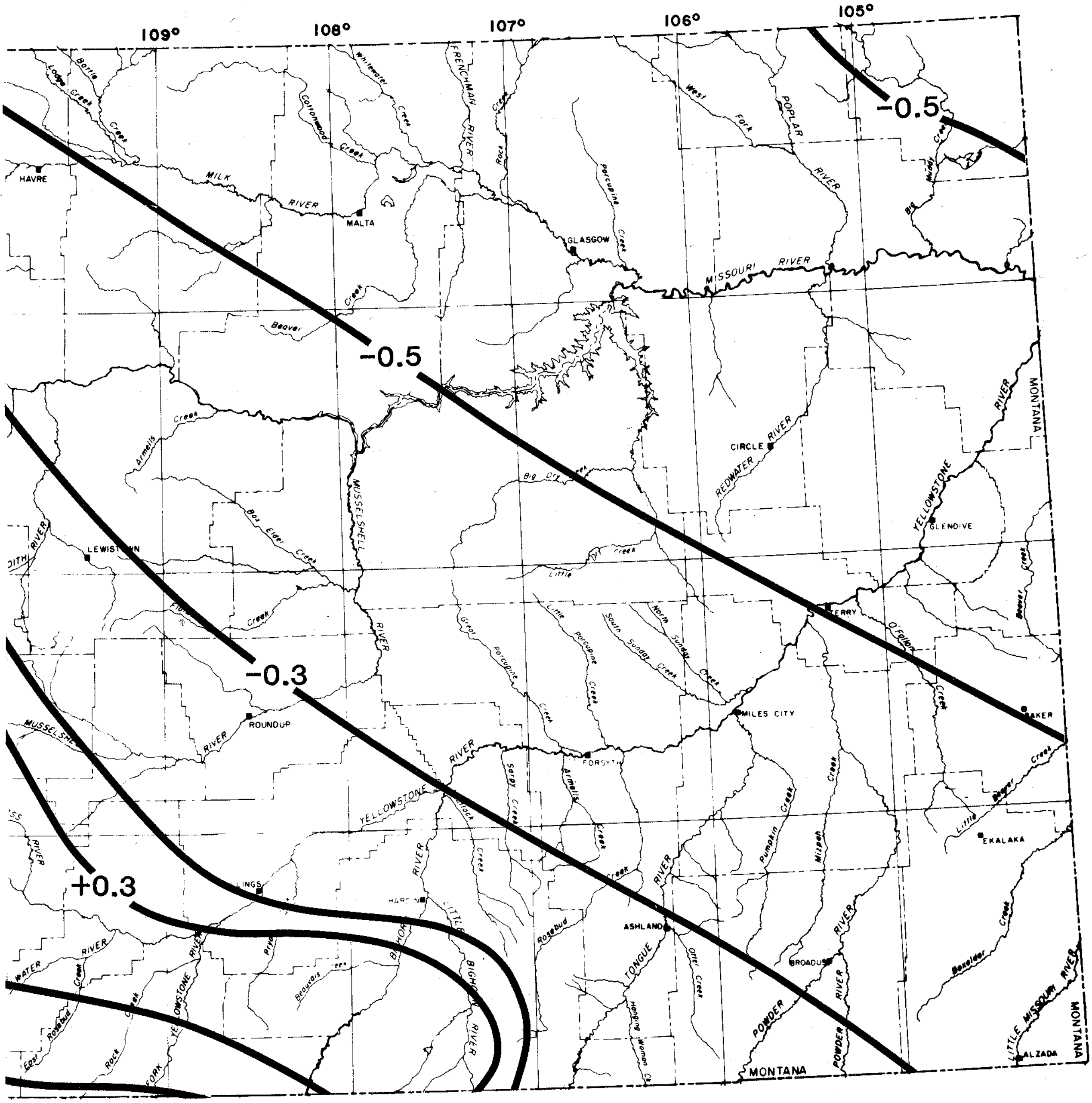


Figure 3.--Generalized skew coefficients of the



Map from S.M. Hamilton (U.S. Soil Conservation Service, Bozeman, Montana, written commun., 1982)

logarithms of annual maximum streamflow.

the U.S. Water Resources Council (1981) represents an improvement over previous maps of skew coefficient. The skew coefficient used at each station was a combination of station skew and regional skew determined by weighting the two values in inverse proportion to their mean square error (MSE) values. Because of the mixed-population frequency analysis made in the Northwest Region, generalized skew coefficients were not applicable in that area.

REGIONAL ANALYSIS OF FLOODS IN RELATION TO HYDROLOGIC CONDITIONS

Flood magnitude and frequency characteristics developed for streamflow-gaging stations were related to drainage-basin and channel-geometry characteristics using multiple-regression techniques to define regional flood-frequency relations. The relationship was made so that flood magnitudes can be estimated for ungaged streams in Montana and for sites on gaged streams when the drainage area at the site differs from the drainage area at the gage by more than 50 percent.

Basin characteristics

The following basin characteristics were investigated for inclusion as independent variables in the regression equations:

A	drainage area;
P	mean annual precipitation;
I_{24-2}	precipitation intensity;
F+10	forest cover index;
E/1000	mean basin elevation index;
HE+10	basin high-elevation index;
JANMIN+10	temperature index;
LAT-44	site latitude index;
LNG-100	site longitude index;
S	main channel slope;
L	mean channel length;
SI	soils storage index; and
LAKE	percentage of basin covered by lakes and ponds.

Basin characteristics determined to be important in the regression equations were drainage area, mean annual precipitation, precipitation intensity, mean basin elevation index, basin high-elevation index, and temperature index. Drainage area was the most significant basin characteristic in all regions. Drainage area, in square miles, is determined for ungaged sites by planimetering the area outlined on the largest scale topographic map available. Mean annual precipitation is the basin average, in inches, determined from the maps contained in the report by the U.S. Soil Conservation Service (1977). Precipitation intensity, in inches, is the maximum 24-hour precipitation having a return period of 2 years or an exceedance probability of 50 percent. Values of I_{24-2} for the East-Central Plains Region are shown in figure 4; I_{24-2} was not a significant characteristic in the other regions.

Mean basin elevation index is the mean basin elevation, in feet above sea-level datum, divided by 1,000. Mean basin elevation can be determined by the grid method from a quadrangle map of a practical scale by laying a grid over the map, recording the elevation at each grid intersection, and averaging those elevations. The basin high-elevation index is the percentage of the total basin area above 6,000 feet

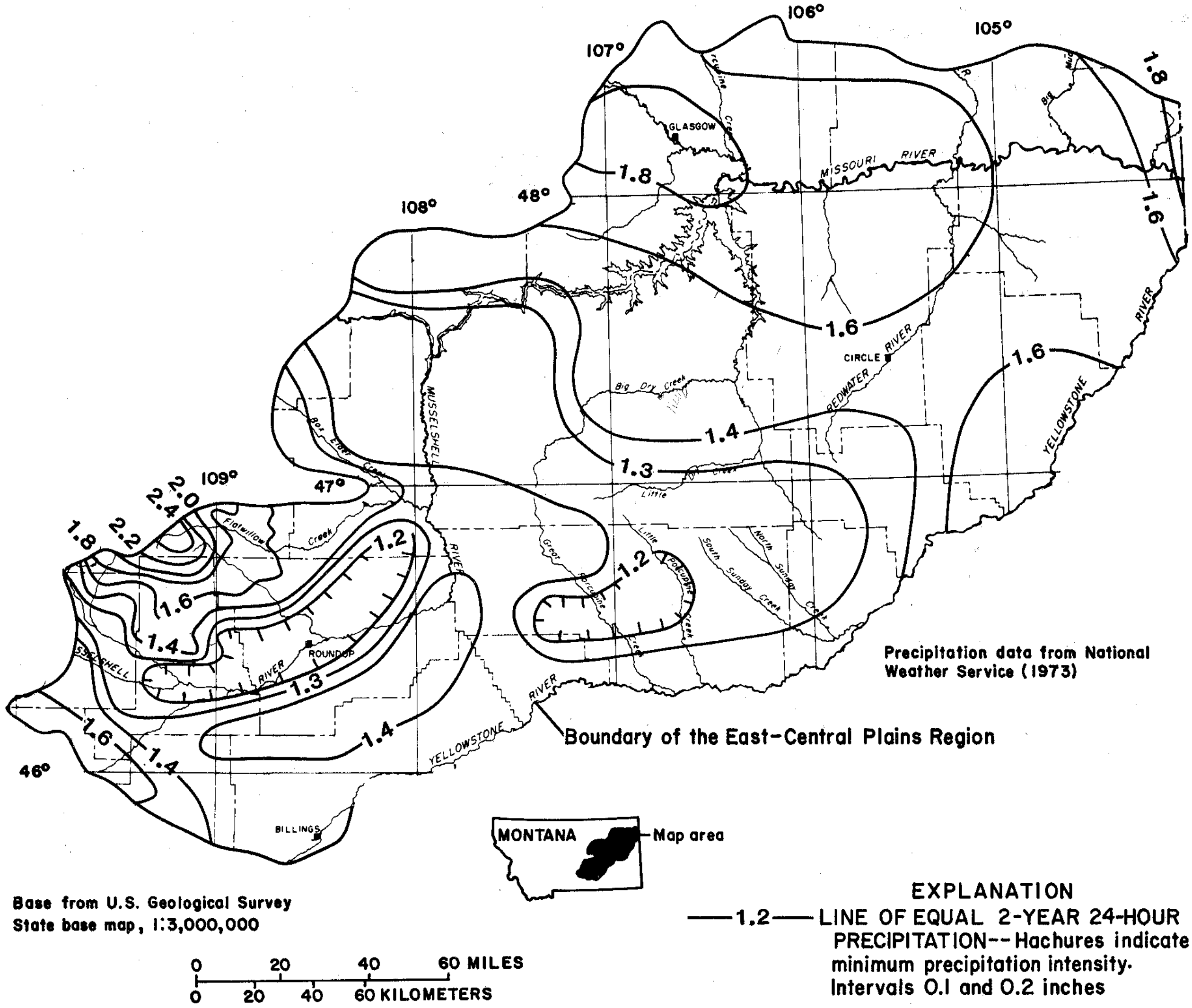


Figure 4.--Precipitation intensity (I_{24-2}) for East-Central Plains Region.

sea-level datum plus 10. The percentage of basin area above 6,000 feet elevation can be determined by planimetering the drainage area above the 6,000-foot contour on a topographic map, multiplying by 100, and dividing the result by the total drainage area. The value 10 is added to the percentage to ensure that a value of zero does not occur in the equations. The temperature index is the mean basin January minimum temperature in degrees Fahrenheit plus 10. Values of JANMIN for the Northeast Plains Region are shown in figure 5; JANMIN was not a significant characteristic in the other regions. The values of the drainage-basin characteristics for each gaging station used in the analysis are listed in table 4. Only the drainage-basin characteristics applicable to each region are included in the table.

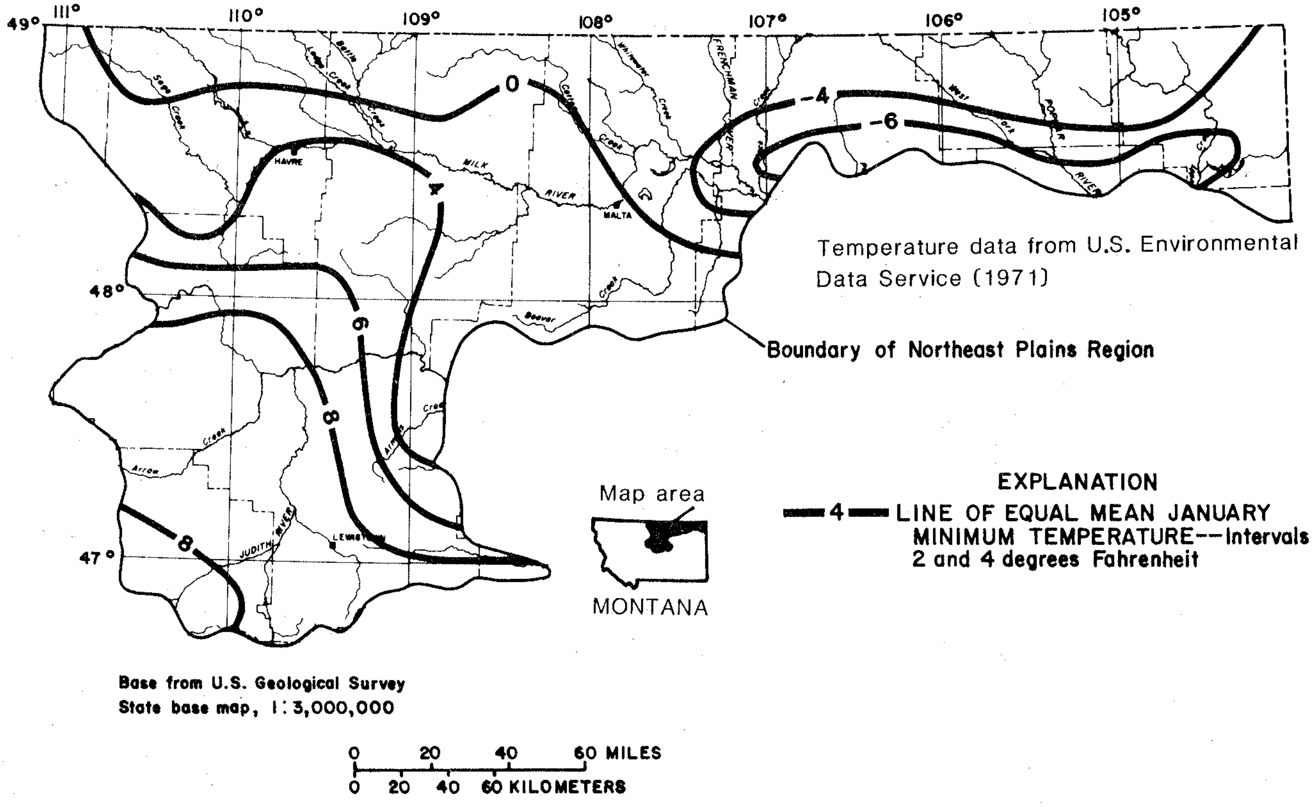


Figure 5.--Mean January minimum temperature (JANMIN) for Northeast Plains Region.

Channel-geometry characteristics

Channel-geometry features were measured at 108 streams with continuous record and 157 streams with partial record. These features were measured during the 1978-80 water years at or near the gaging station where peak-flow data were available. Active-channel width (W_{AC}) was determined to be significant in the Upper Yellowstone-Central Mountain Region and the Southwest Region. Bankfull width (W_{BF}) was significant in the West Region. Channel-geometry characteristics were significant in the other regions but the features had not been measured at a sufficient number of stations to include them in the analysis. Measurement of all streams could improve future analyses.

The channel-geometry method, which is described in reports by Parrett and others (1983) and Omang and others (1983), provides equations for the entire State. These equations use flood-frequency data through the 1978 water year. Values for the channel-geometry characteristics used in the analysis, along with the basin characteristics applicable to each region, are listed in table 5 in the "Supplemental Data" section at the end of this report.

Regression analysis

Equations for estimating maximum discharges for selected exceedance probabilities were developed from multiple-regression analyses of streamflow, basin-characteristic, and channel-geometry data obtained at streamflow-gaging stations. The data were transformed to logarithms to help ensure a linear relationship among the variables, and regression equations of the following form were derived:

$$\text{Log } Q_t = \log K + a \log A + b \log B + \ldots + n \log N \qquad (1)$$

where

Q_t, the dependent variable, is flood magnitude having exceedance probability t;
K is multiple-regression constant;
A, B, . . . N are values of drainage-basin characteristics and channel-geometry characteristics (independent variable); and
a, b, . . . n are regression coefficients.

After taking antilogarithms, the resulting equations are of the form:

$$Q_t = K A^a B^b \ldots N^n \qquad (2)$$

The regression analyses were performed by digital computer using Statistical Analysis System (SAS)[1] programs (SAS Institute, Inc., 1979). These programs provide various statistical measures of the applicability of the derived regression equations such as standard errors of estimate, coefficients of determination (R^2), and tests for the significance of each independent variable.

Two sets of regression equations for estimating Q_t were developed. One set considered only drainage-basin characteristics as independent variables and included all stations used in the analysis. Another set considered both basin characteristics and channel-geometry characteristics as independent variables but only included stations where channel geometry had been measured. For example, the West Region has basin characteristic data available for 70 streamflow-gaging stations but only 47 stations in the regions have information available on channel geometry.

In developing equations containing both basin characteristics and channel geometry, a "maximum R^2 improvement" routine for adding or deleting independent variables was used. This procedure determines the "best" one-independent-variable equation (largest R^2), the best two-independent-variable equation (greatest increase in R^2), and so forth until all independent variables have been added to the model. In this study, independent variables were examined, and the computer routine was run until six of the independent variables were included in the equations. The equations thus derived were examined, and, in all instances, the standard error of estimate for the best three-variable model was only slightly larger than for the

[1]Use of the trade name in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

best four-, five-, or six-variable model. In fact, in seven regions the best two-variable model had a standard error of estimate only slightly larger than any of the models having more variables. Consequently, the final estimating equations were limited to a maximum of three independent variables.

Initially, the same regional boundaries for the eight regions used in the study by Parrett and Omang (1981) were used in this analysis. These boundaries were determined by plotting on a map the regression residuals (difference between the Q_t predicted from the regression equation and the Q_t determined from the station data-frequency curve). The plotted residuals were examined for groupings of similar magnitude and then used to divide the State into the eight regions. Drainage divides were used as regional boundaries where feasible. Some of the boundaries changed because new stations not used in the previous analysis indicated that the boundaries needed to be slightly different. Separate multiple-regression analyses were then made for each of the eight regions. A further refinement of the final equations was made by plotting antilogarithms of regression residuals for $Q_{1\%}$ on a State map and connecting equal values. The lines thus drawn represent a geographical factor (G_f) that is used as a multiplier in the mathematical model. The geographical factor (fig. 6) can be determined from the map for use in the equations presented in table 1.

The final regression equations developed for each region and the standard errors of estimate with and without the geographical factor incorporated into the regression equation are given in table 1. A sensitivity test was performed on the regression equations, for the 1 percent exceedance probability, for all the regions. This test was done by assuming all variables are constant except the one being tested for sensitivity. No large percentage difference on the computed discharge was determined by varying the error of the variable. Intercorrelation of the independent variables also was investigated, with no discernable intercorrelation of the independent variables used for the final equations. The flood magnitude was determined for the new sites not used in the previous analysis (Parrett and Omang, 1981) using their prediction equations and the geographical factor developed for that report. In most instances, the predicted value was much closer to the actual value using the geographical factor. Therefore, a geographical factor was used in this report.

The final regression equations developed for the regions where channel geometry was significant are given in table 2. The geographical factor is not included in these equations because there were not enough stations to develop a representative geographical factor for the State. An estimate of the desired flood magnitude can be made by using the equations given in tables 1 and 2. To use the equations in table 2, a site visit is neccessary for measurement of the channel geometry. A site visit is not needed to use the equations in table 1. Personal judgment of the stream in question and knowledge of the area, validity of the channel-geometry measurements, and evaluation of the standard error of estimate for both sets of equations can be used to determine whether to use the equations in table 1 or table 2 or whether to average the two sets of equations. The relationships presented in this report provide more reliable estimates of flood magnitudes than those in previous studies, because of a larger data base, more gaging stations on smaller drainage areas closer in size to those used by planners and design engineers, and improved analytical procedures.

Limitations of regression equations

The regression equations provide a means for determining flood magnitudes for selected exceedance probabilities for ungaged streams in Montana and for sites on gaged streams where the drainage area at the site differs from the drainage area at the gage by more than 50 percent. The equations were developed from gaging-station data where the flood flows are virtually unaffected by urbanization, regulation, or diversion.

The regression equations also will not be valid where unique, localized geologic features affect floods. These features would include areas where a large part of the streamflow results from springs or seeps and areas where soils are so permeable that unusual volumes of runoff are absorbed.

The regression equations generally are not usable for determining $Q_{2\%}$ and $Q_{1\%}$ in the Northwest-Foothills Region for any stream that originates in the Northwest Region. Streams that originate in the Northwest Region have a large $Q_{2\%}$ and $Q_{1\%}$ as a result of intense rains from southern sources. As these streams drain from the mountains and enter the relatively flat plains area of the Northwest-Foothills Region, the high flows are largely attenuated by valley storage. Thus, the maximum discharges at downstream locations commonly are the same as or less than the maximum discharges at upstream locations. The $Q_{2\%}$ and $Q_{1\%}$ contribution from the Northwest Region can be calculated by using basin characteristics at the region boundary, but determining whether $Q_{2\%}$ and $Q_{1\%}$ increase, stay constant, or decrease with increasing downstream drainage area requires careful, individual study of the stream in question.

Flood magnitudes for streams that cross other regional boundaries can be determined by a weighting procedure as discussed in the "Estimating Floods" section of this report. The procedure also applies to determining flood magnitudes for exceedance probabilities other than 2 percent and 1 percent for streams that drain from the Northwest to the Northwest-Foothills Regions.

The estimating relations in this report are known to apply only within the range of variables tested or sampled. For this study, the range in values of basin and channel characteristics used is given in table 3. Extrapolation beyond the range of values listed may not give reliable results.

It is important to remember that the equations yield estimates of flood magnitude based on records of gaged streams. The designer or hydrologist responsible for making flood estimates needs to be aware that, in instances of unusual circumstances, the regression equations may provide unreliable results. When such instances can be identified, additional study, knowledge of hydrologic conditions in a specific area including historic floods and streamflow measured at the site, or onsite visits are needed to decide among alternative estimating techniques.

Accuracy appraisal

The accuracy of a regression equation generally is measured by the standard error of estimate. The standard error of estimate is a measure of the standard deviation of the distribution of residuals about the regression line and usually is expressed in percentage of the estimated value when log-transformed variables are used. The regression value is within the range of error (standard error of estimate) at about two of every three sites and is within twice this range at about 19 of every 20 sites. The standard error of estimate is a measure of how well the computed flood peaks agree with the observed flood peaks and is not necessarily a

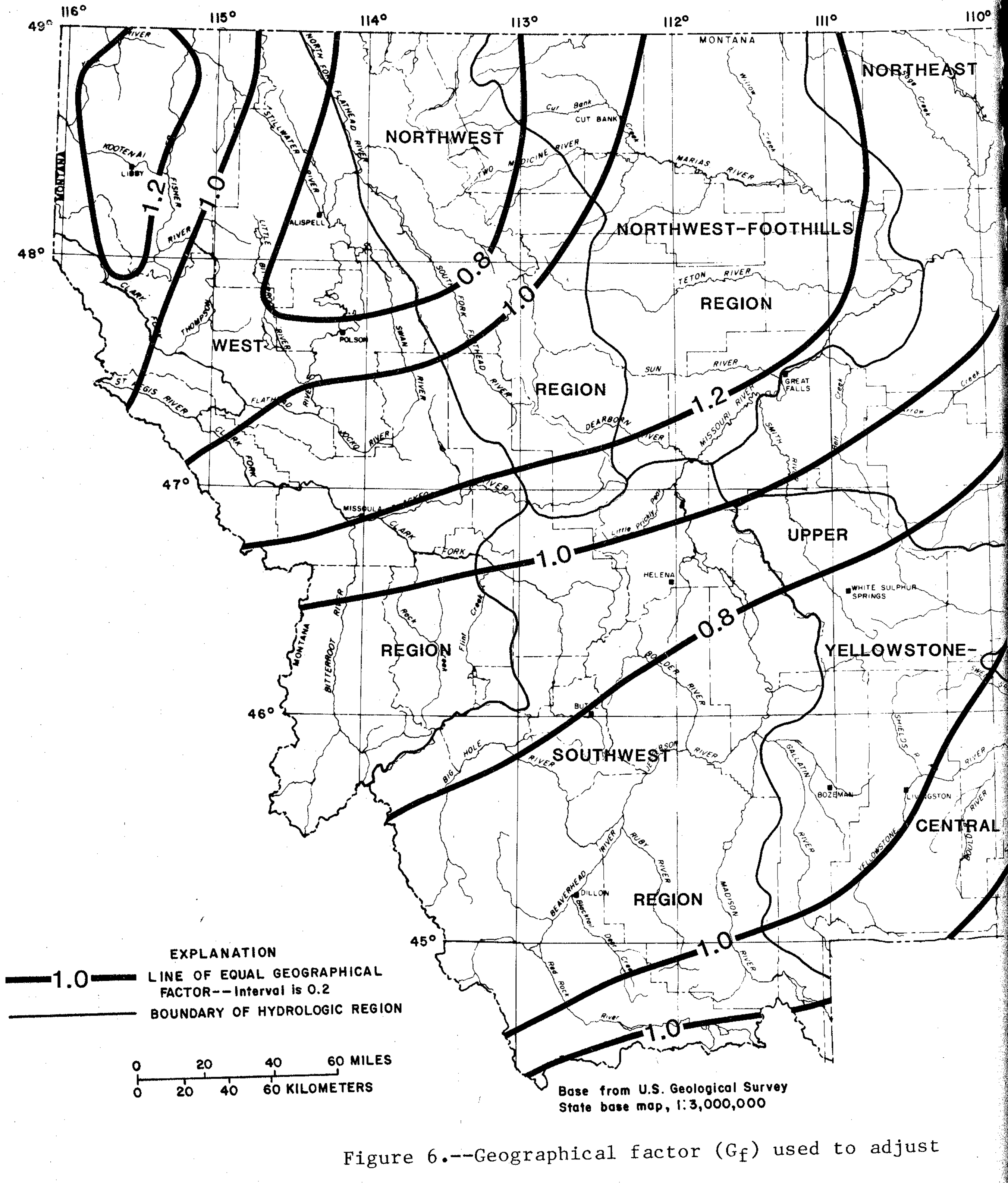
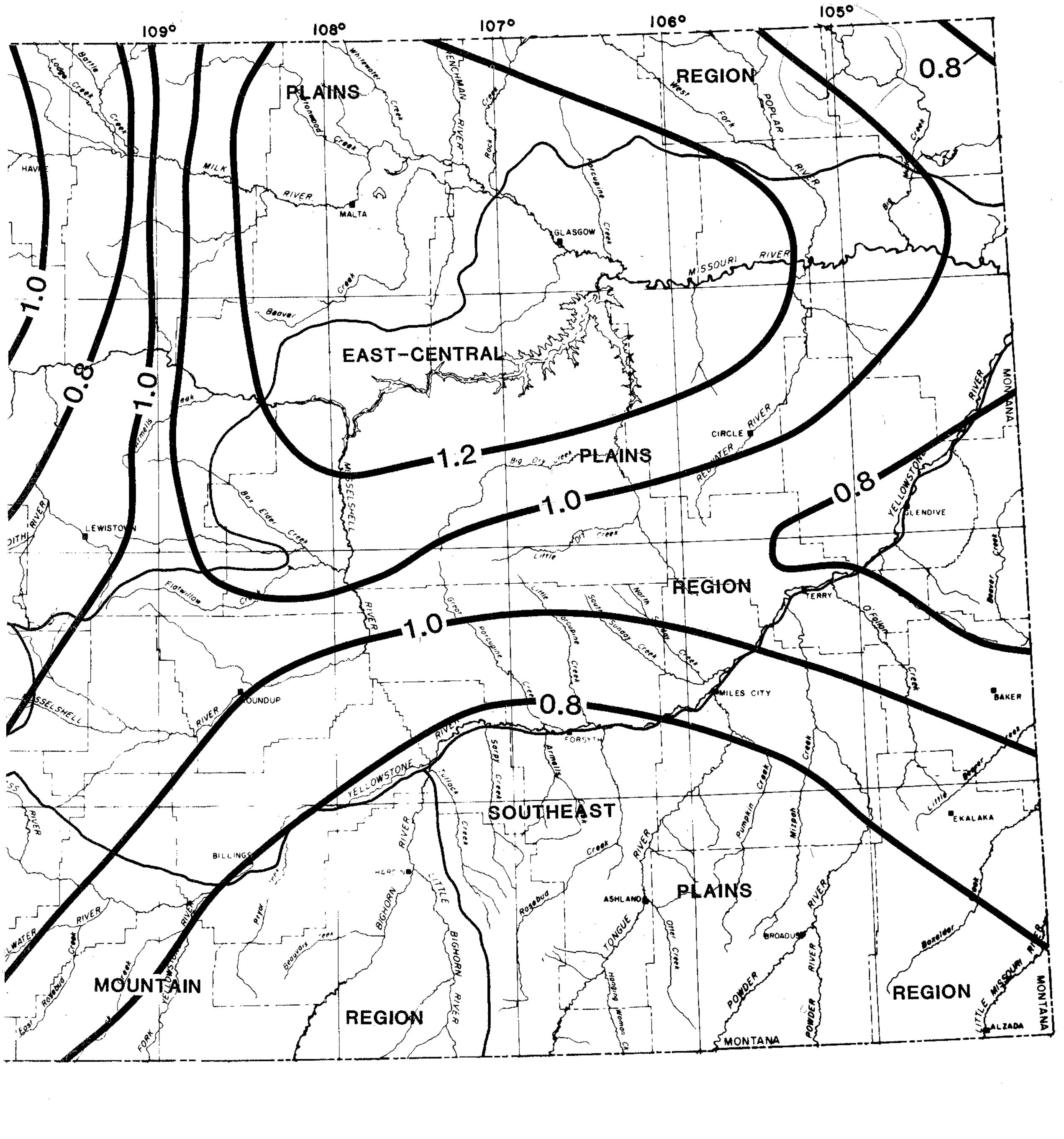


Figure 6.--Geographical factor (G_f) used to adjust

measure of how well the equation can be used to estimate or predict from data not used in the regression analysis. It is only one indicator of the reliability of a prediction equation.



the regionalized calculation of flood discharges.

Table 1.--*Regional flood-frequency equations based on basin characteristics*

[A, drainage area; P, mean annual precipitation; G_f, geographical factor; HE+10, basin high-elevation index; E/1000, mean basin elevation index; JANMIN+10, temperature index; I_{24-2}, precipitation intensity]

Discharge (cubic feet per second for given exceedance probability)		Equations	Recurrence interval (years)	Standard error of estimate (percent) With G_f	Standard error of estimate (percent) Without G_f
		West Region (70 stations)			
$Q_{50\%}$	=	$0.037\ A^{0.95}P^{1.52}G_f$	2	49	51
$Q_{20\%}$	=	$0.112\ A^{0.89}P^{1.38}G_f$	5	43	46
$Q_{10\%}$	=	$0.192\ A^{0.86}P^{1.32}G_f$	10	42	45
$Q_{4\%}$	=	$0.324\ A^{0.84}P^{1.26}G_f$	25	43	46
$Q_{2\%}$	=	$0.451\ A^{0.82}P^{1.22}G_f$	50	43	46
$Q_{1\%}$	=	$0.594\ A^{0.80}P^{1.20}G_f$	100	43	49
		Northwest Region (26 Stations)			
$Q_{50\%}$	=	$0.343\ A^{0.89}P^{1.12}G_f$	2	47	43
$Q_{20\%}$	=	$3.23\ A^{0.82}P^{0.72}G_f$	5	39	36
$Q_{10\%}$	=	$11.1\ A^{0.78}P^{0.51}G_f$	10	39	33
$Q_{4\%}$	=	$36.3\ A^{0.75}P^{0.32}G_f$	25	36	33
$Q_{2\%}$	=	$54.2\ A^{0.73}P^{0.34}G_f$	50	32	33
$Q_{1\%}$	=	$75.2\ A^{0.71}P^{0.39}G_f$	100	45	43
		Southwest Region (50 Stations)			
$Q_{50\%}$	=	$2.68\ A^{0.90}(HE+10)^{0.13}G_f$	2	78	78
$Q_{20\%}$	=	$24.4\ A^{0.81}(HE+10)^{-0.17}G_f$	5	64	66
$Q_{10\%}$	=	$83.4\ A^{0.78}(HE+10)^{-0.34}G_f$	10	64	64
$Q_{4\%}$	=	$324\ A^{0.74}(HE+10)^{-0.55}G_f$	25	64	67

Table 1.--*Regional flood-frequency equations based on basin characteristics*--Continued

Discharge (cubic feet per second for given exceedance probability)		Equations	Recurrence interval (years)	Standard error of estimate (percent) With G_f	Standard error of estimate (percent) Without G_f
$Q_{2\%}$	=	$802\ A^{0.71}(HE+10)^{-0.68}G_f$	50	68	70
$Q_{1\%}$	=	$1{,}850\ A^{0.69}(HE+10)^{-0.81}G_f$	100	72	74
		Upper Yellowstone-Central Mountain Region (64 stations)			
$Q_{50\%}$	=	$0.285\ A^{0.82}(E/1000)^{3.41}(HE+10)^{-0.67}G_f$	2	58	58
$Q_{20\%}$	=	$1.87\ A^{0.77}(E/1000)^{3.44}(HE+10)^{-0.96}G_f$	5	45	46
$Q_{10\%}$	=	$5.31\ A^{0.75}(E/1000)^{3.46}(HE+10)^{-1.12}G_f$	10	42	45
$Q_{4\%}$	=	$16.6\ A^{0.72}(E/1000)^{3.41}(HE+10)^{-1.27}G_f$	25	43	46
$Q_{2\%}$	=	$34.8\ A^{0.71}(E/1000)^{3.37}(HE+10)^{-1.36}G_f$	50	46	49
$Q_{1\%}$	=	$69.3\ A^{0.69}(E/1000)^{3.34}(HE+10)^{-1.45}G_f$	100	49	53
		Northwest-Foothills Region (23 Stations)			
$Q_{50\%}$	=	$1.05\ A^{0.51}(E/1000)^{2.22}G_f$	2	85	96
$Q_{20\%}$	=	$6.98\ A^{0.52}(E/1000)^{1.64}G_f$	5	54	61
$Q_{10\%}$	=	$15.4\ A^{0.52}(E/1000)^{1.51}G_f$	10	49	54
$Q_{4\%}$	=	$32.5\ A^{0.52}(E/1000)^{1.47}G_f$	25	49	51
$Q_{2\%}$	=	$50.1\ A^{0.51}(E/1000)^{1.49}G_f$	50	43	53
$Q_{1\%}$	=	$68.4\ A^{0.50}(E/1000)^{1.59}G_f$	100	57	60
		Northeast Plains Region (61 Stations)			
$Q_{50\%}$	=	$21.7\ A^{0.65}(JANMIN+10)^{-0.23}G_f$	2	75	73
$Q_{20\%}$	=	$104\ A^{0.61}(JANMIN+10)^{-0.39}G_f$	5	56	54

Table 1.--*Regional flood-frequency equations based on basin characteristics*--Continued

Discharge (cubic feet per second for given exceedance probability)		Equations	Recurrence interval (years)	Standard error of estimate (percent) With G_f	Standard error of estimate (percent) Without G_f
$Q_{10\%}$	=	$201\ A^{0.58}(JANMIN+10)^{-0.42}G_f$	10	51	50
$Q_{4\%}$	=	$361\ A^{0.56}(JANMIN+10)^{-0.42}G_f$	25	51	51
$Q_{2\%}$	=	$492\ A^{0.54}(JANMIN+10)^{-0.39}G_f$	50	53	54
$Q_{1\%}$	=	$625\ A^{0.53}(JANMIN+10)^{-0.36}G_f$	100	57	58
		East-Central Plains Region (54 Stations)			
$Q_{50\%}$	=	$42.8\ A^{0.36}I_{24-2}{}^{-0.46}G_f$	2	92	94
$Q_{20\%}$	=	$73.6\ A^{0.39}I_{24-2}{}^{0.92}G_f$	5	72	75
$Q_{10\%}$	=	$101\ A^{0.40}I_{24-2}{}^{1.50}G_f$	10	69	73
$Q_{4\%}$	=	$143\ A^{0.40}I_{24-2}{}^{2.01}G_f$	25	72	77
$Q_{2\%}$	=	$180\ A^{0.40}I_{24-2}{}^{2.28}G_f$	50	75	80
$Q_{1\%}$	=	$224\ A^{0.40}I_{24-2}{}^{2.49}G_f$	100	82	87
		Southeast Plains Region (55 Stations)			
$Q_{50\%}$	=	$389\ A^{0.51}(E/1000)^{-2.40}G_f$	2	116	124
$Q_{20\%}$	=	$957\ A^{0.52}(E/1000)^{-2.30}G_f$	5	80	83
$Q_{10\%}$	=	$1{,}370\ A^{0.53}(E/1000)^{-2.18}G_f$	10	66	72
$Q_{4\%}$	=	$1{,}940\ A^{0.54}(E/1000)^{-2.02}G_f$	25	66	67
$Q_{2\%}$	=	$2{,}370\ A^{0.54}(E/1000)^{-1.91}G_f$	50	67	69
$Q_{1\%}$	=	$2{,}750\ A^{0.55}(E/1000)^{-1.79}G_f$	100	70	72

Table 2.--*Regional flood-frequency equations based on channel-geometry and basin characteristics*

Discharge (cubic feet per second for given exceedance probability)		Equations	Recurrence interval (years)	Standard error of estimate (percent)
		West Region (47 Stations)		
$Q_{50\%}$	=	$0.041\ A^{0.47}P^{0.86}W_{BF}^{1.14}$	2	45
$Q_{20\%}$	=	$0.139\ A^{0.44}P^{0.73}W_{BF}^{1.07}$	5	38
$Q_{10\%}$	=	$0.258\ A^{0.42}P^{0.67}W_{BF}^{1.05}$	10	36
$Q_{4\%}$	=	$0.465\ A^{0.40}P^{0.61}W_{BF}^{1.02}$	25	36
$Q_{2\%}$	=	$0.663\ A^{0.38}P^{0.58}W_{BF}^{1.01}$	50	38
$Q_{1\%}$	=	$0.899\ A^{0.37}P^{0.55}W_{BF}^{1.00}$	100	39
		Southwest Region (42 Stations)		
$Q_{50\%}$	=	$0.56\ W_{AC}^{1.59}(HE+10)^{0.25}$	2	69
$Q_{20\%}$	=	$6.07\ W_{AC}^{1.43}(HE+10)^{-0.06}$	5	60
$Q_{10\%}$	=	$22.3\ W_{AC}^{1.36}(HE+10)^{-0.24}$	10	61
$Q_{4\%}$	=	$93.8\ W_{AC}^{1.28}(HE+10)^{-0.45}$	25	66
$Q_{2\%}$	=	$240\ W_{AC}^{1.25}(HE+10)^{-0.59}$	50	69
$Q_{1\%}$	=	$570\ W_{AC}^{1.21}(HE+10)^{-0.72}$	100	75
		Upper Yellowstone-Central Mountain Region (49 Stations)		
$Q_{50\%}$	=	$4.14\ A^{0.21}(HE+10)^{-0.17}W_{AC}^{1.28}$	2	58
$Q_{20\%}$	=	$29.6\ A^{0.24}(HE+10)^{-0.44}W_{AC}^{1.15}$	5	53
$Q_{10\%}$	=	$87.1\ A^{0.27}(HE+10)^{-0.58}W_{AC}^{1.05}$	10	54
$Q_{4\%}$	=	$269\ A^{0.29}(HE+10)^{-0.74}W_{AC}^{0.99}$	25	57
$Q_{2\%}$	=	$550\ A^{0.29}(HE+10)^{-0.84}W_{AC}^{0.96}$	50	58
$Q_{1\%}$	=	$1,090\ A^{0.30}(HE+10)^{-0.93}W_{AC}^{0.92}$	100	63

Table 3.--*Range of basin and channel-geometry characteristics*

Region	Drainage area (A) (square miles)	Mean annual precipitation (P) (inches)	Mean basin elevation (E) (feet)	Basin above 6,000 feet elevation (HE) (percent)	Mean minimum January temperature (JANMIN) (degrees Fahrenheit)	Precipitation intensity (I_{24-2}) (inches)	Active channel width (W_{AC}) (feet)	Bankfull width (W_{BF}) (feet)
West	0.86-524	19-79	--	--	--	--	--	7.5-136
Northwest	2.38-510	15-105	--	--	--	--	--	--
Southwest	0.48-538	--	--	0-100	--	--	1.0-85	--
Upper Yellowstone-Central Mountain	1.48-543	--	2,850-9,560	0-100	--	--	2.5-120	--
Northwest-Foothills	0.25-397	--	2,750-5,130	--	--	--	--	--
Northeast Plains	0.11-534	--	--	--	(-5)-(+10)	--	--	--
East-Central Plains	0.22-547	--	--	--	--	1.2-1.8	--	--
Southeast Plains	0.04-587	--	2,100-4,650	--	--	--	--	--

The standard error of estimate for each regression equation is given in tables 1 and 2. The largest standard errors using only basin characteristics occur generally in the East-Central Plains and Southeast Plains Regions. Conversely, the smallest standard errors occur in the Northwest and West Regions. In all regions, the largest standard error occurs in the $Q_{50\%}$ prediction equation.

The standard errors of estimate in table 1, using only basin characteristics, represent an improvement for most of the exceedance probabilities in all regions over results in the study of Johnson and Omang (1976) and in all regions except the Northeast Plains and Southwest Regions over results in the study of Parrett and Omang (1981). The standard errors of estimate for the final estimating relations in this report without using the G_f factor are an improvement over the $Q_{1\%}$ and $Q_{2\%}$ equations in the Parrett and Omang (1981) report for all regions except the Upper Yellowstone-Central Mountain Region where the error was 4 percent greater for $Q_{1\%}$ and 1 percent greater for $Q_{2\%}$ and the Northeast Plains Region where the error was 1 percent greater for $Q_{2\%}$. The best improvement was in the East-Central Plains and Southeast Plains Regions.

The standard errors using channel-geometry and basin characteristics (table 2) were smaller for the West Region, about equal in the Southwest Region, and greater in the Upper Yellowstone-Central Mountain Region compared to the standard errors using just basin characteristics. The standard errors using channel-geometry characteristics probably could be improved by measuring the feature at all stations in each region.

Maximum known floods

Floods of record are plotted versus the corresponding drainage areas for gaging stations within each region in figures 7-14. Also shown in these figures is a curve relating the 1-percent-chance flood magnitudes to drainage areas for the region. The 1-percent-chance flood relation was determined from regression equations using drainage area as the only independent variable. In addition, a curve relating the maximum known floods in the United States to drainage areas is shown. The data in figures 7-14 provide a comparison of Montana's flood experience with the national flood experience.

ESTIMATING FLOODS

Flood magnitudes may be estimated directly at an ungaged site near a gaged site on the same stream when the ungaged drainage area does not differ from the gaged drainage area by more than about 50 percent. The estimate can be computed according to the following equation, which is based on the drainage-area ratio of the ungaged site to the gaged site:

$$\hat{Q}_t = \left(\frac{Au}{Ag}\right)^a \cdot Q_t \qquad (3)$$

where

$\hat{Q}_t$ is flood magnitude being estimated with exceedance probability t,
Au is drainage area at the ungaged site,
Ag is drainage area at the gaged site,
a is exponent of drainage area for the appropriate region and desired exceedance probability as given in table 1, and
Q_t is flood magnitude at the gaged site based on the appropriate exceedance probability from table 4.

The relation in equation 3 will be unreliable if used to predict $Q_{1\%}$ and $Q_{2\%}$ for streams where the ungaged site is in the Northwest-Foothills Region and the gaged site is in the Northwest Region.

On large streams having several gaged sites or sites where flood-magnitude estimates have been made for National Flood Insurance Studies, flood magnitudes between the sites can be interpolated from curves relating flood magnitude to drainage-area size. The relationship of flood magnitude to drainage area for all major

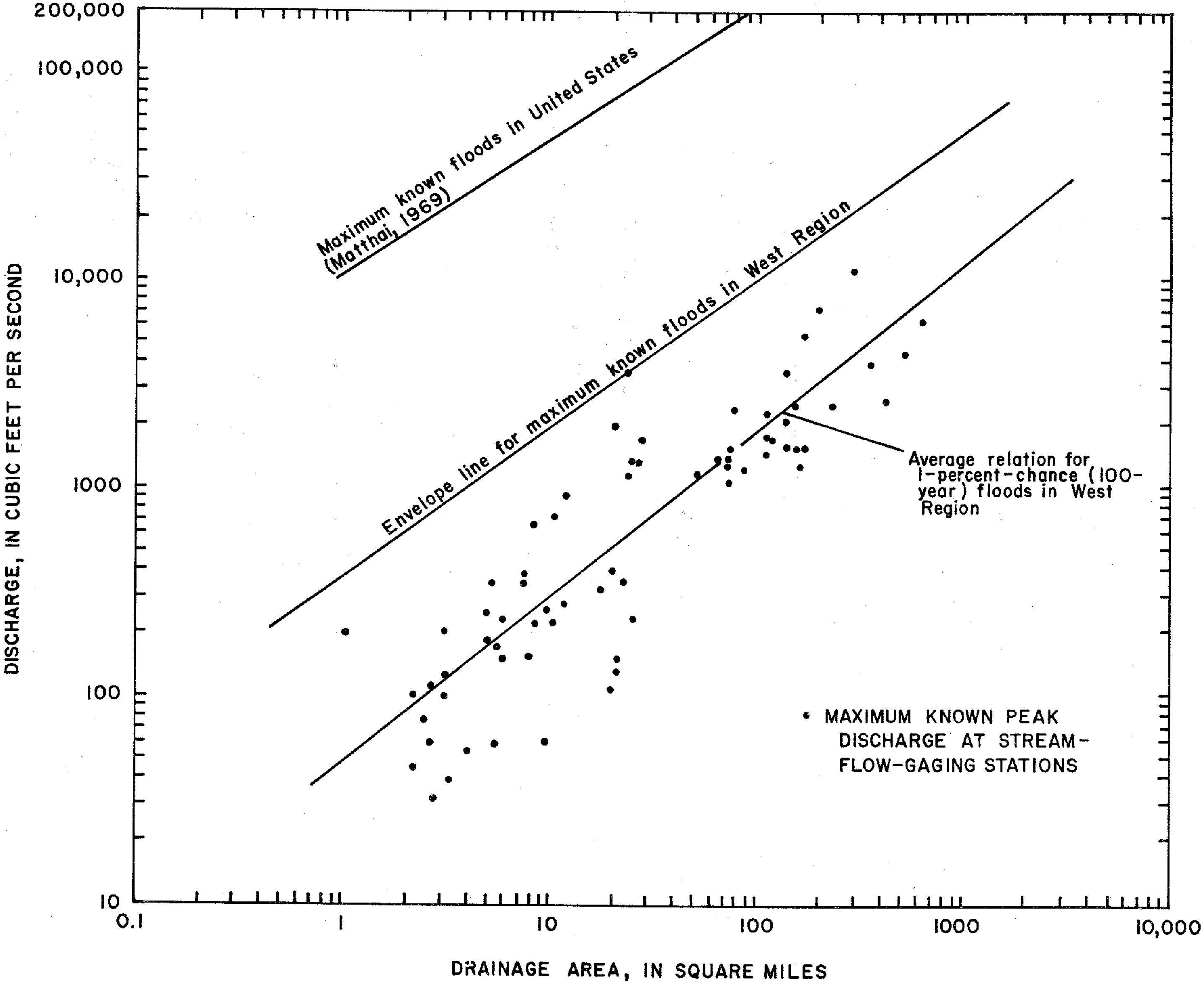


Figure 7.--Relation of maximum known peak discharge to drainage area in the West Region.

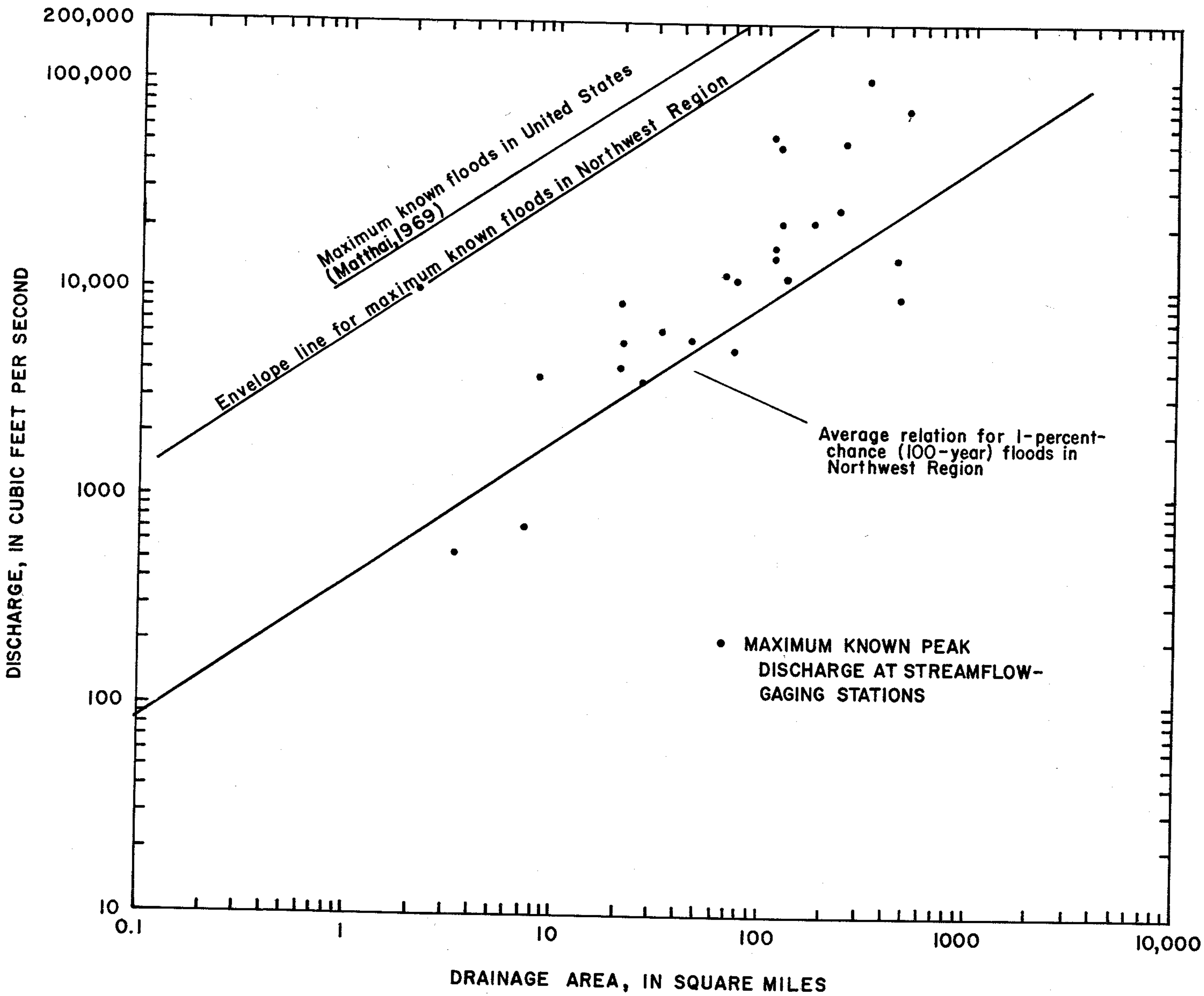


Figure 8.--Relation of maximum known peak discharge to drainage area in the Northwest Region.

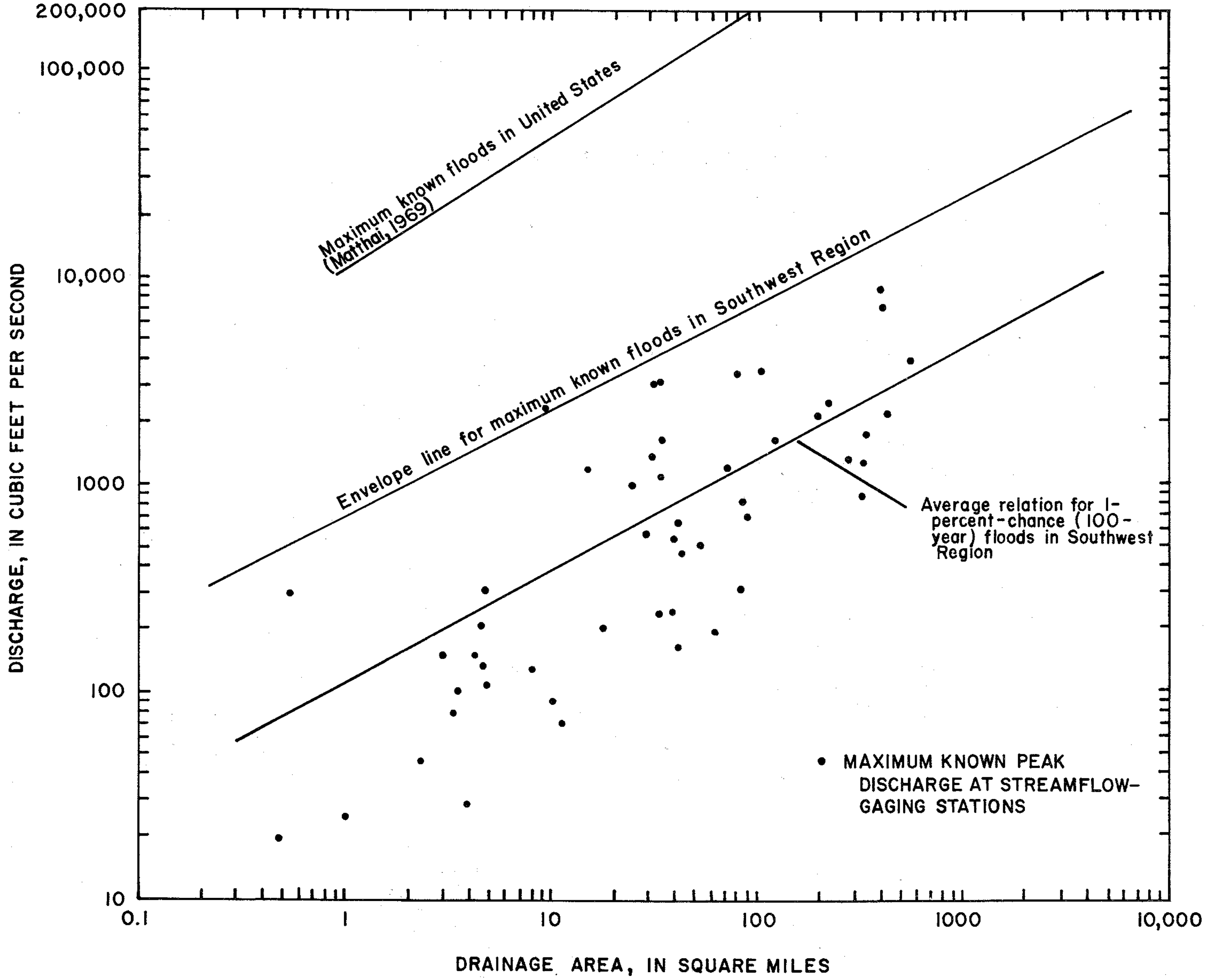


Figure 9.--Relation of maximum known peak discharge to drainage area in the Southwest Region.

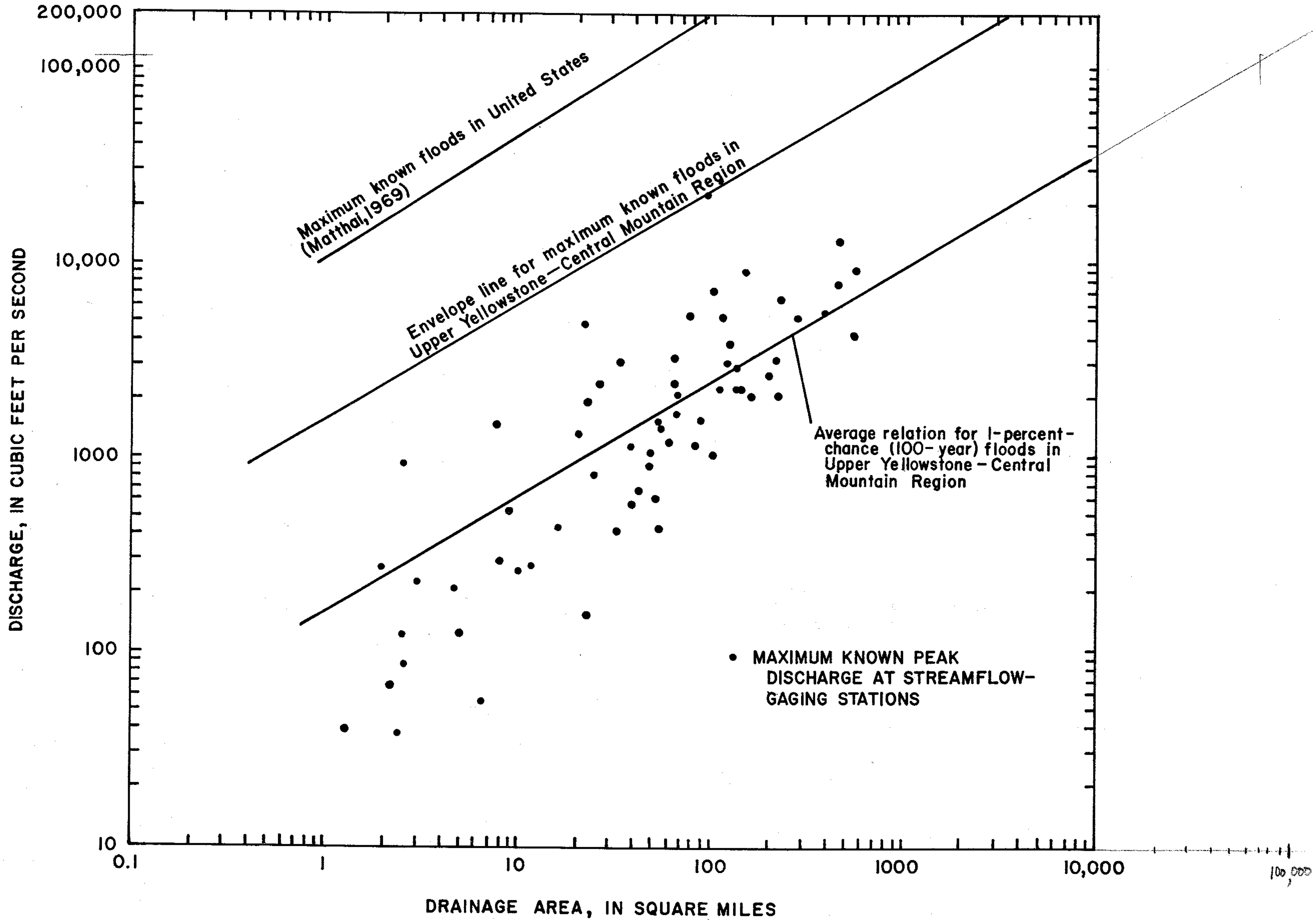


Figure 10.--Relation of maximum known peak discharge to drainage area in the Upper Yellowstone-Central Mountain Region.

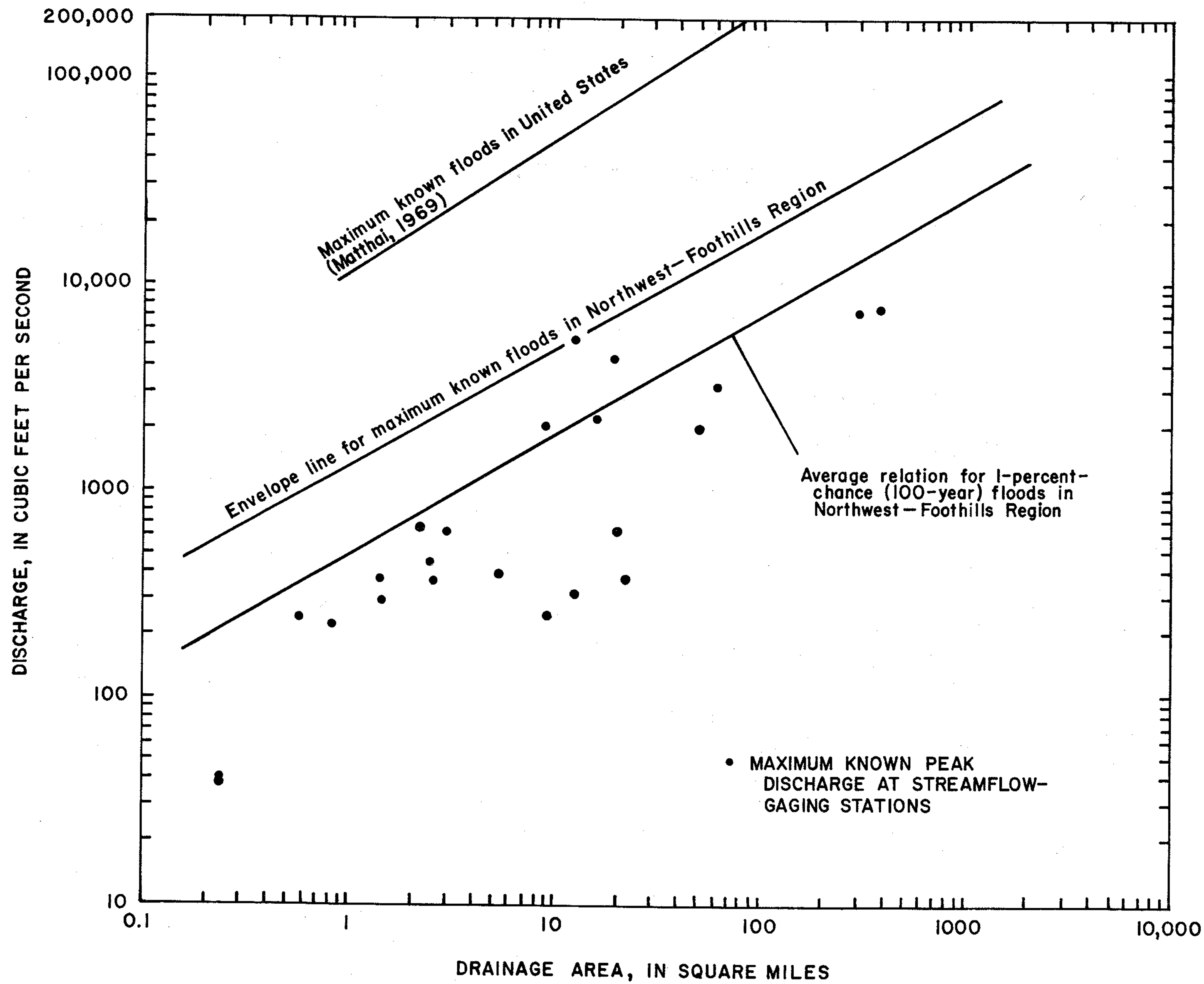


Figure 11.--Relation of maximum known peak discharge to drainage area in the Northwest-Foothills Region.

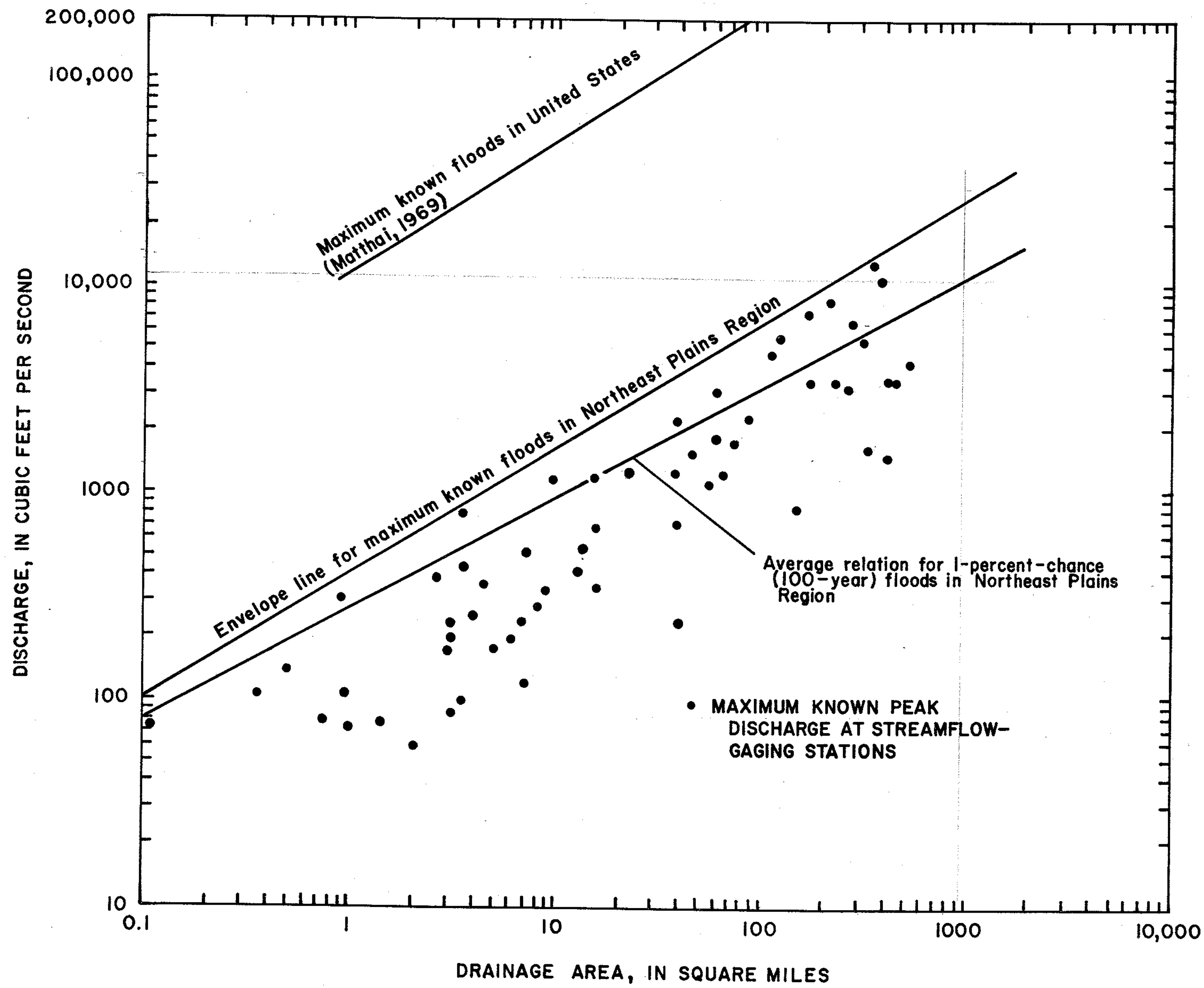


Figure 12.--Relation of maximum known peak discharge to drainage area in the Northeast Plains Region.

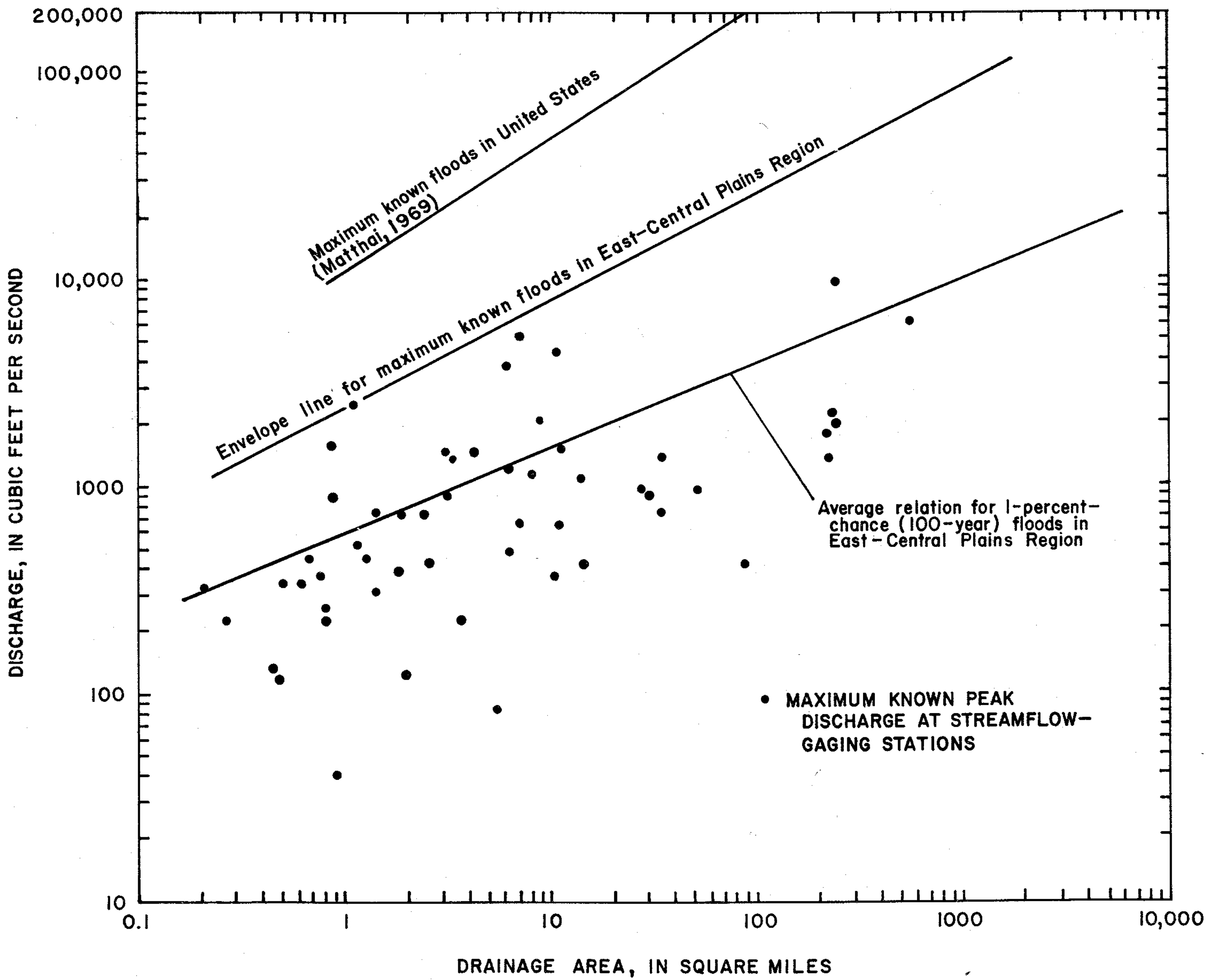


Figure 13.--Relation of maximum known peak discharge to drainage area in the East-Central Plains Region.

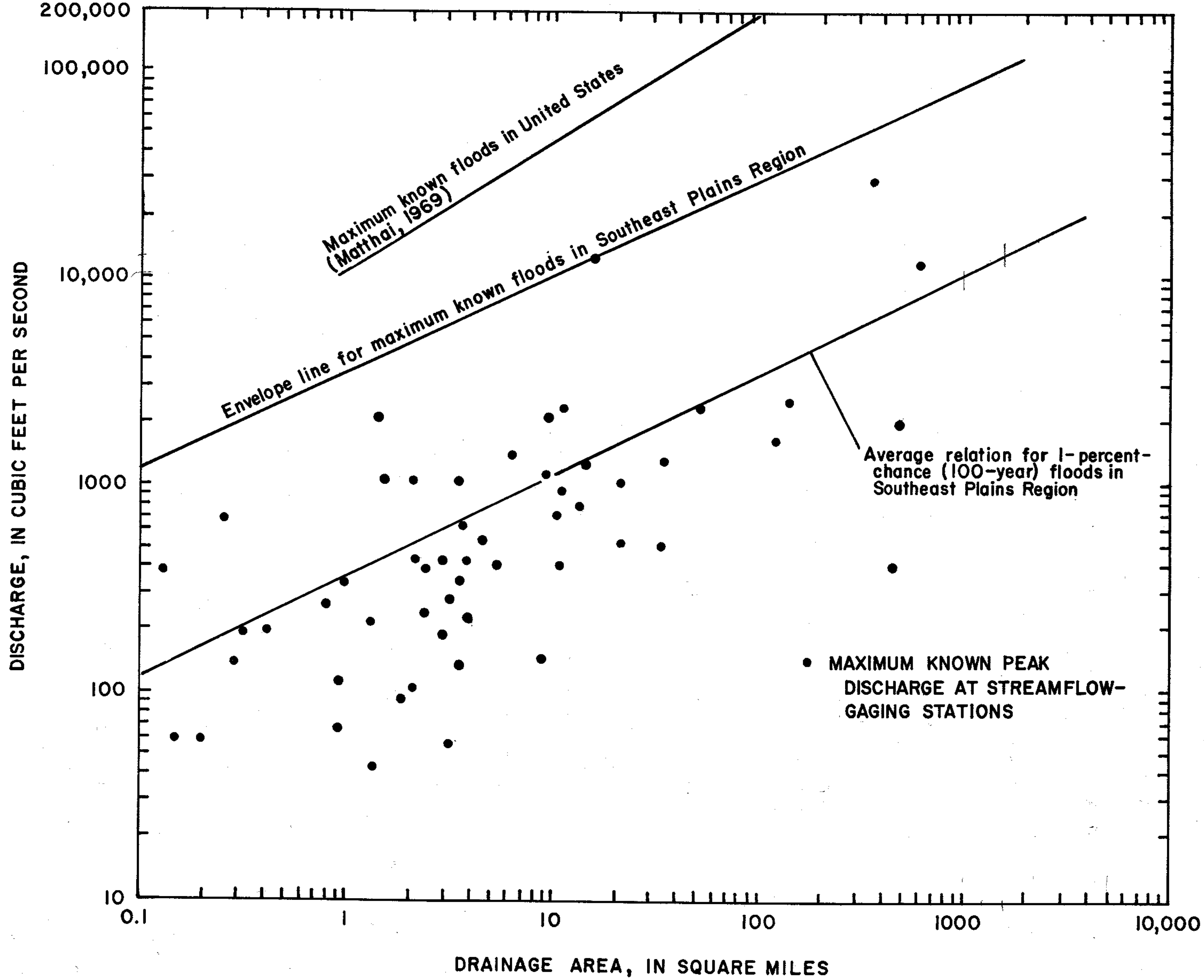


Figure 14.--Relation of maximum known peak discharge to drainage area in the Southeast Plains Region.

streams in Montana where interpolation was considered to be applicable is presented in figures 15-22. For ungaged sites with drainages smaller than those shown in figures 15-22, the appropriate regression equation needs to be used to estimate flood magnitude. Diversions and regulation that occur between some sites may significantly affect $Q_{50\%}$. For example, on the Milk (fig. 17) and Musselshell (fig. 19) Rivers, $Q_{50\%}$ decreases between two sites having increasing drainage area. $Q_{2\%}$ and $Q_{1\%}$ also decrease between three sites having increasing drainage area on the Musselshell River -- apparently as a result of valley storage.

To determine flood magnitudes for selected exceedance probabilities for any ungaged site in Montana, locate the site on the map (fig. 1) and determine in which region it is located and if it is on a gaged stream.

1. If the site is on the Bitterroot, Clark Fork, Milk, Missouri, Musselshell, Powder, Sun, or Yellowstone River, interpolate the desired flood magnitudes from the discharge versus drainage-area curves in figures 15-22.

2. If the site is on a gaged stream and has a drainage area within 5 percent of that of the nearest gage, use the flood magnitudes for the gage given in table 4.

3. If the site is on an ungaged stream, or on a gaged stream where the drainage area at the site differs from the drainage area at the gage by more than 50 percent, use the appropriate regression equation to calculate flood magnitudes as follows:

   a. Select the appropriate regression equation from table 1, based on the region the site is in; and

   b. Determine the required basin characteristics from figures 4-6, the best available topographic map, and precipitation data from the U.S. Soil Conservation Service (1977).

4. If the site is on a gaged stream and has a drainage area within 50 percent of that at the gage, use equation 3 to determine the desired flood magnitudes.

5. If the site is on an ungaged stream, and a site visit has been made to measure the channel-geometry features, use the appropriate regression equation to calculate flood magnitudes as follow:

   a. Select the appropriate regression equation from table 2, based on the region the site is in; and

   b. Determine the required basin characteristics from the best available topographic map and precipitation data from the U.S. Soil Conservation Service (1977).

6. If the drainage basin for the site in question lies in two regions, determine a weighted average flood magnitude as follows:

   a. Using the total drainage area and the appropriate regression equation, determine the flood magnitude that would result if the entire drainage were located within each of the two regions;

b. Measure that part of the total drainage area that lies in each of the two adjoining regions;

c. Multiply the flood magnitude determined in step a for each region by the ratio of the drainage area within that region to the total drainage area and add the two results to obtain a weighted average flood magnitude.

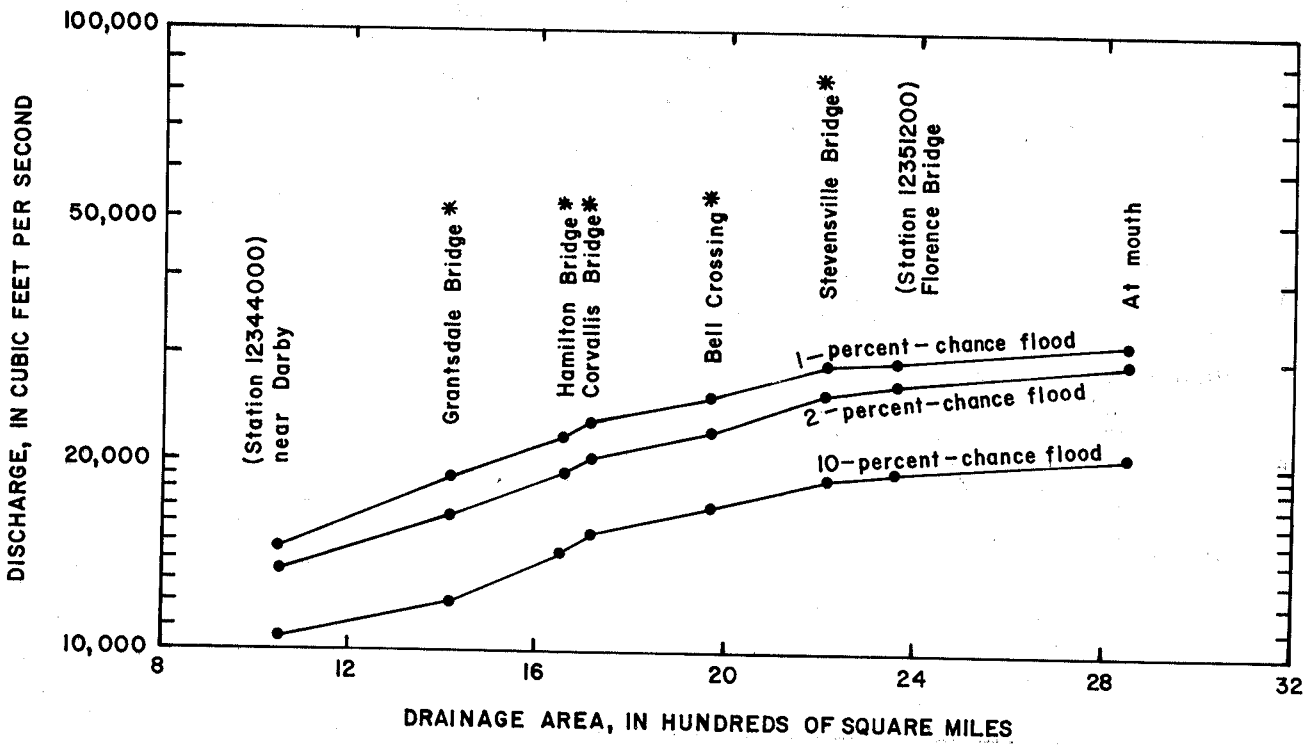


Figure 15.--Relation of discharge to drainage area for selected flood frequencies along the main stem of the Bitterroot River. Asterisk denotes flood magnitude determined for National Flood Insurance Study.

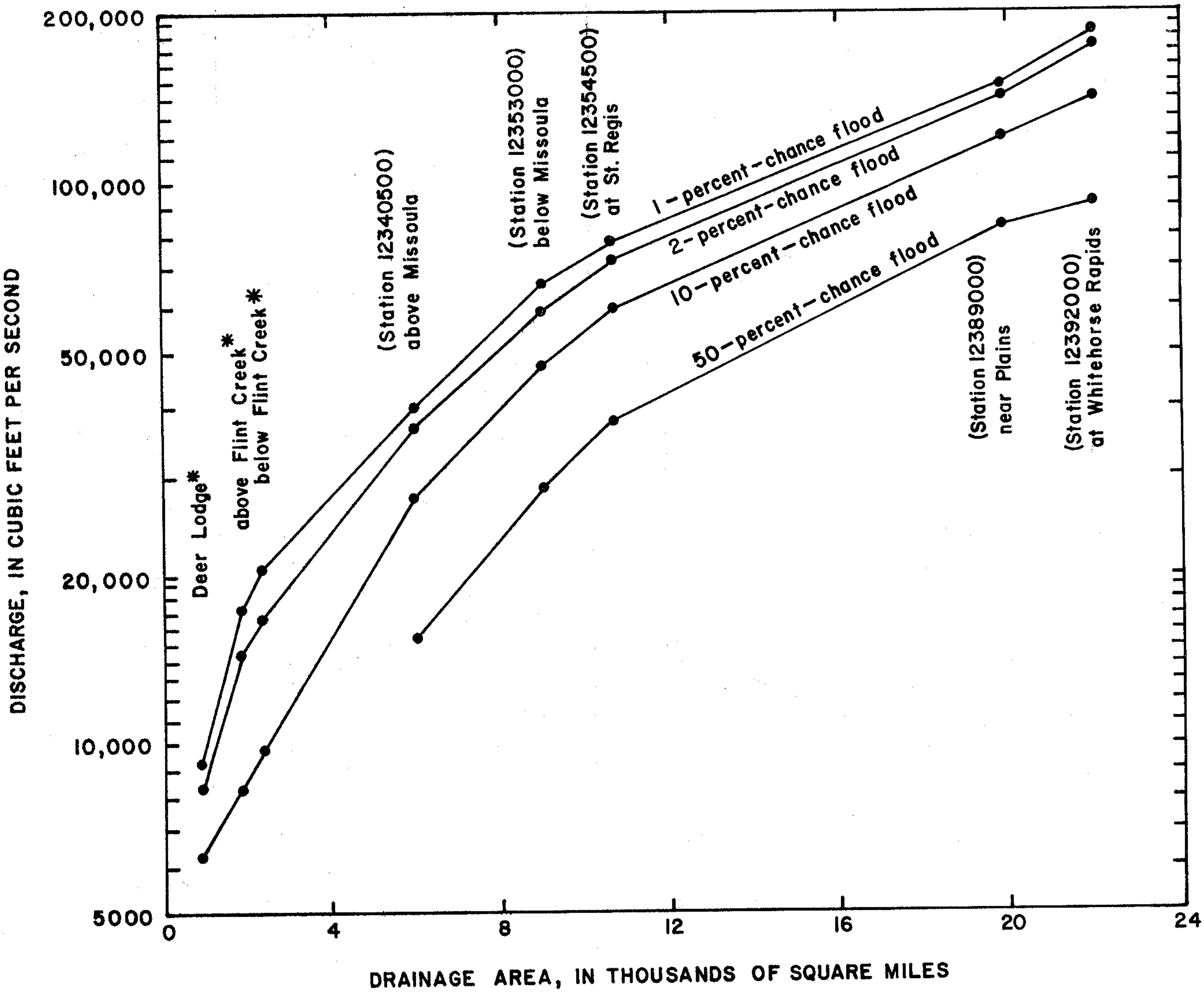


Figure 16.--Relation of discharge to drainage area for selected flood frequencies along the main stem of the Clark Fork River. Asterisk denotes flood magnitude determined for National Flood Insurance Study.

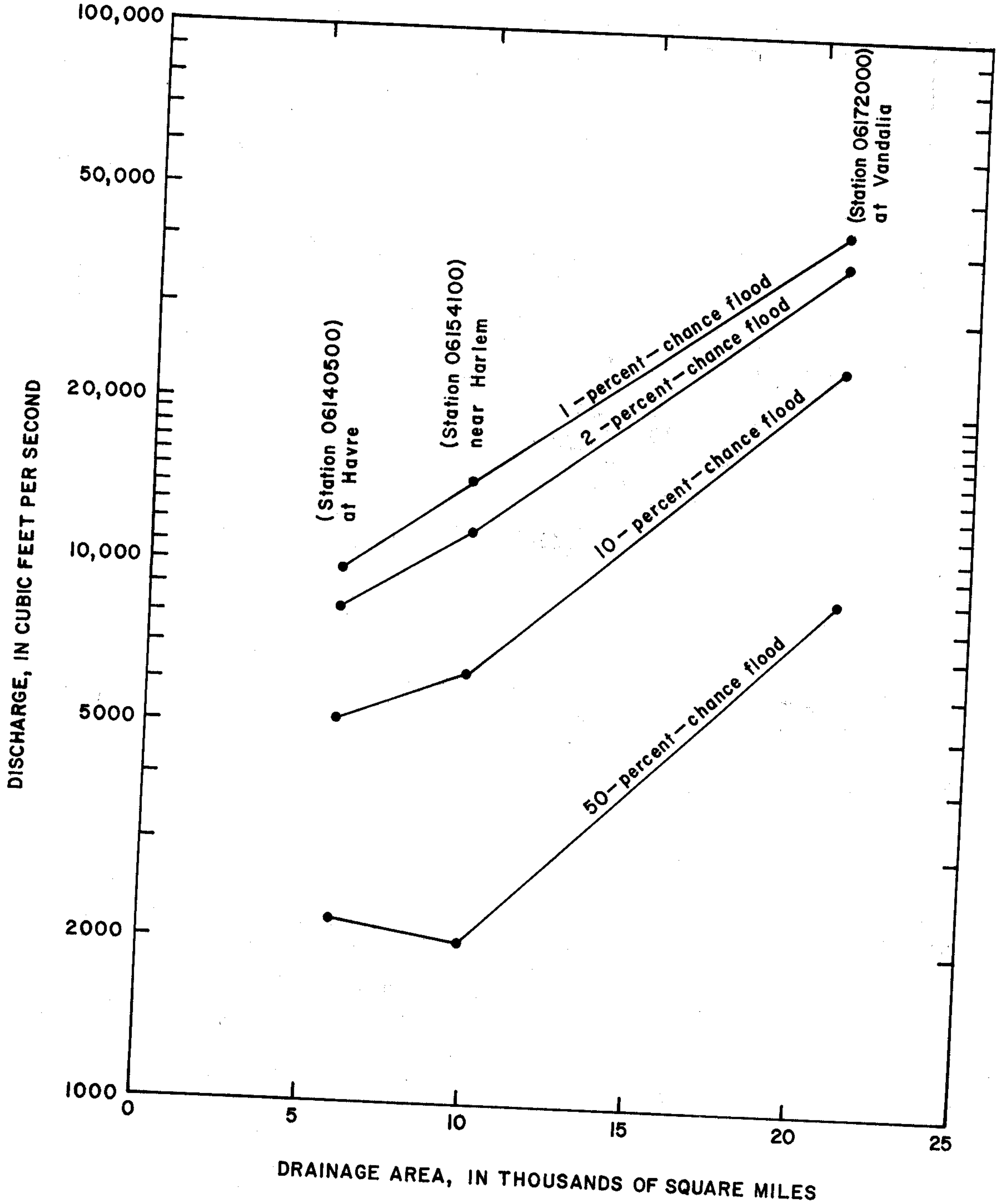


Figure 17.--Relation of discharge to drainage area for selected flood frequencies along the main stem of the Milk River.

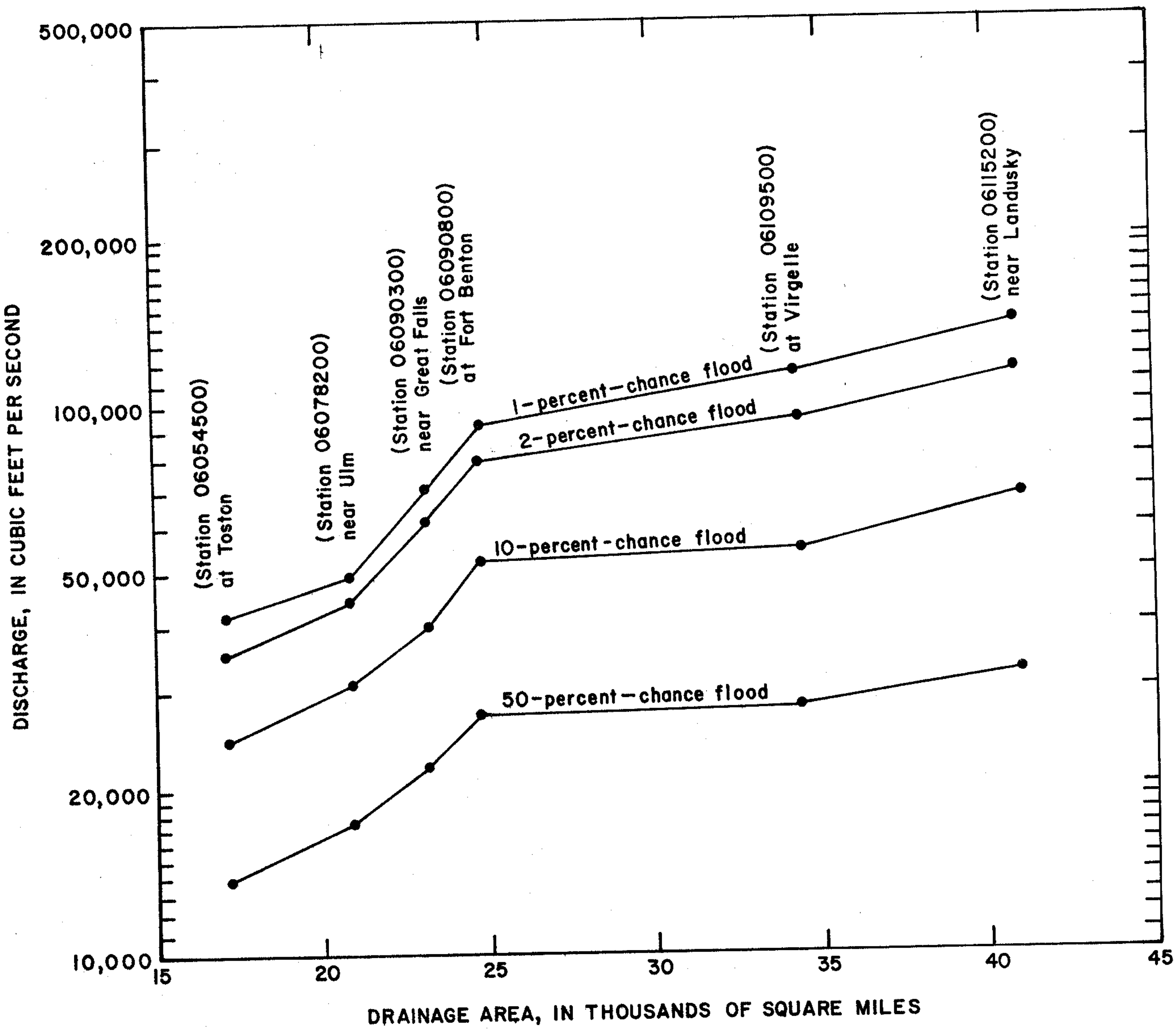


Figure 18.--Relation of discharge to drainage area for selected flood frequencies along the main stem of the Missouri River.

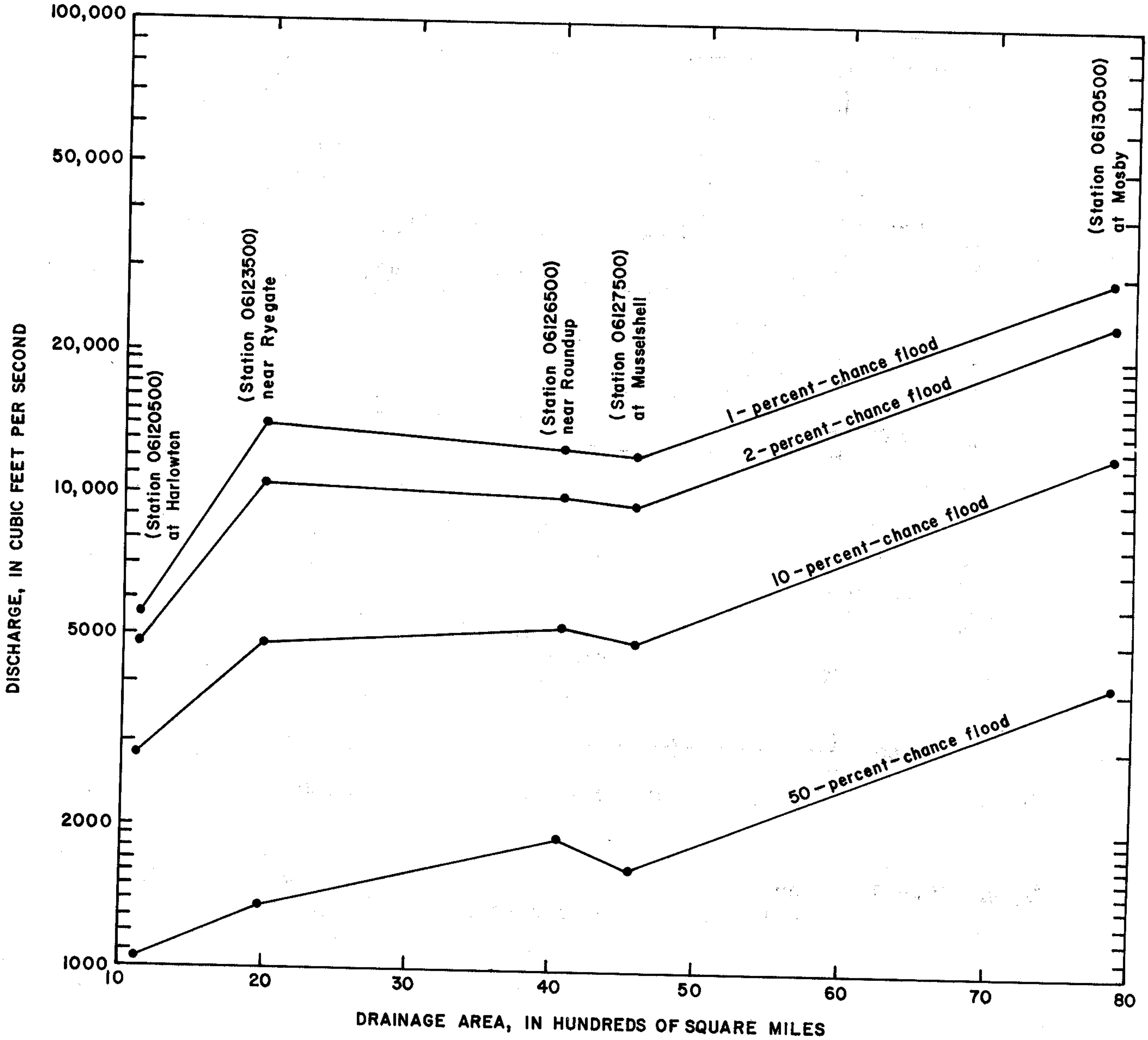


Figure 19.--Relation of discharge to drainage area for selected flood frequencies along the main stem of the Musselshell River.

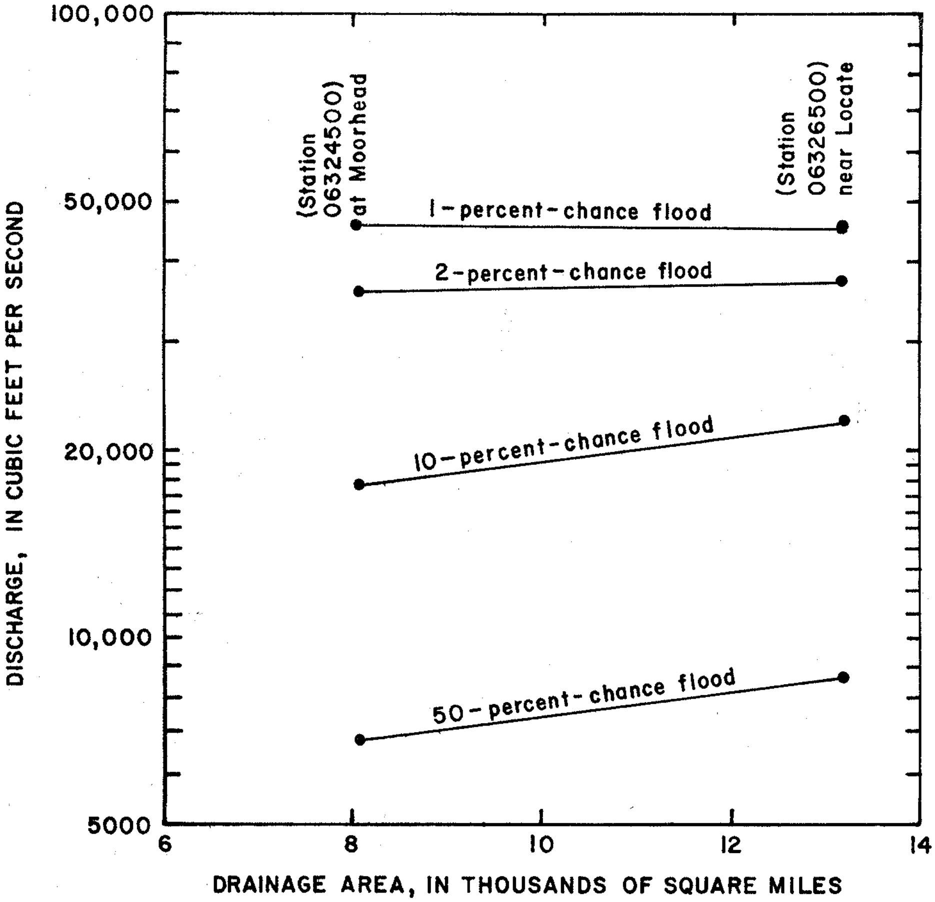


Figure 20.--Relation of discharge to drainage area for selected flood frequencies along the main stem of the Powder River.

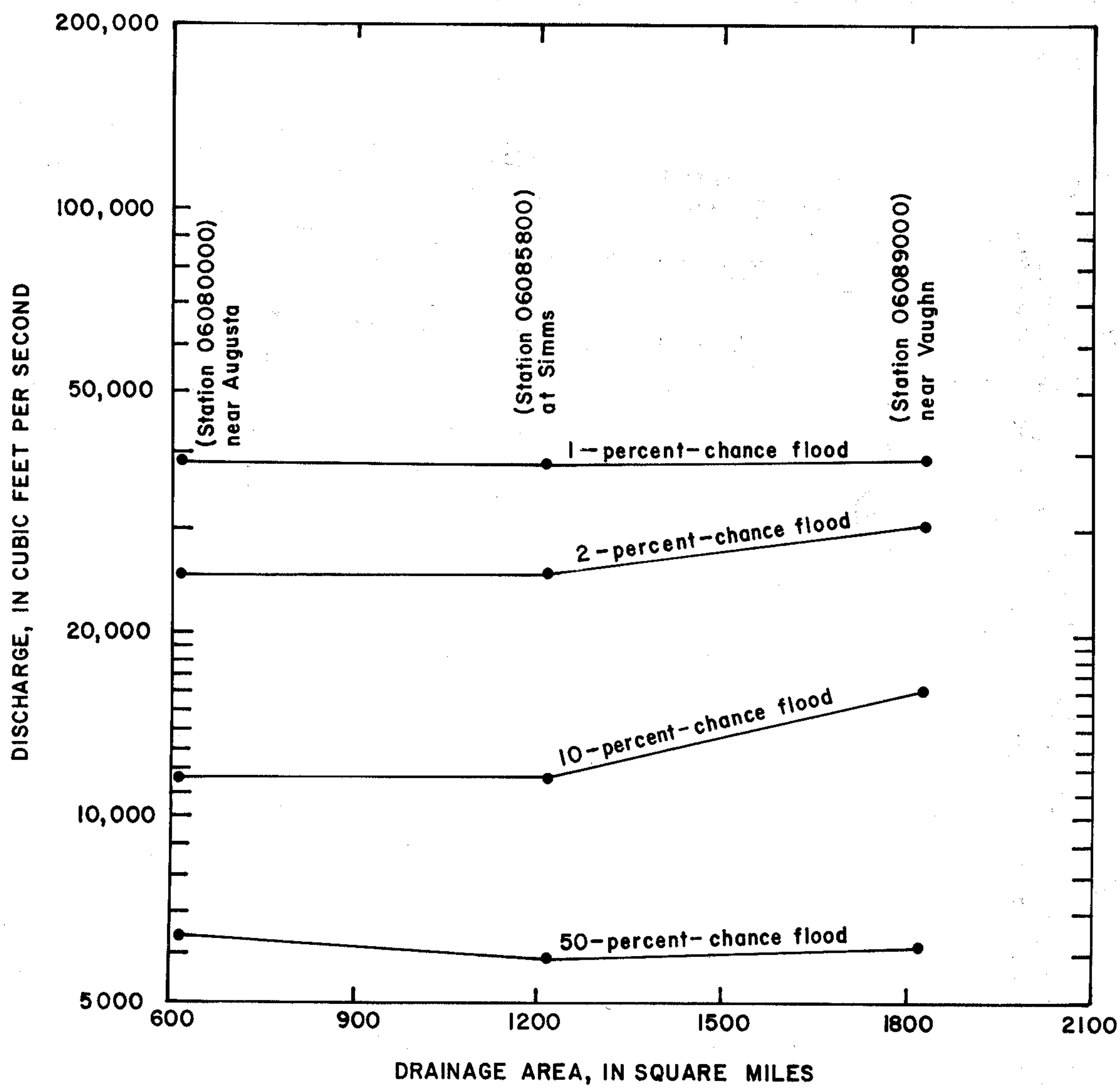


Figure 21.--Relation of discharge to drainage area for selected flood frequencies along the main stem of the Sun River.

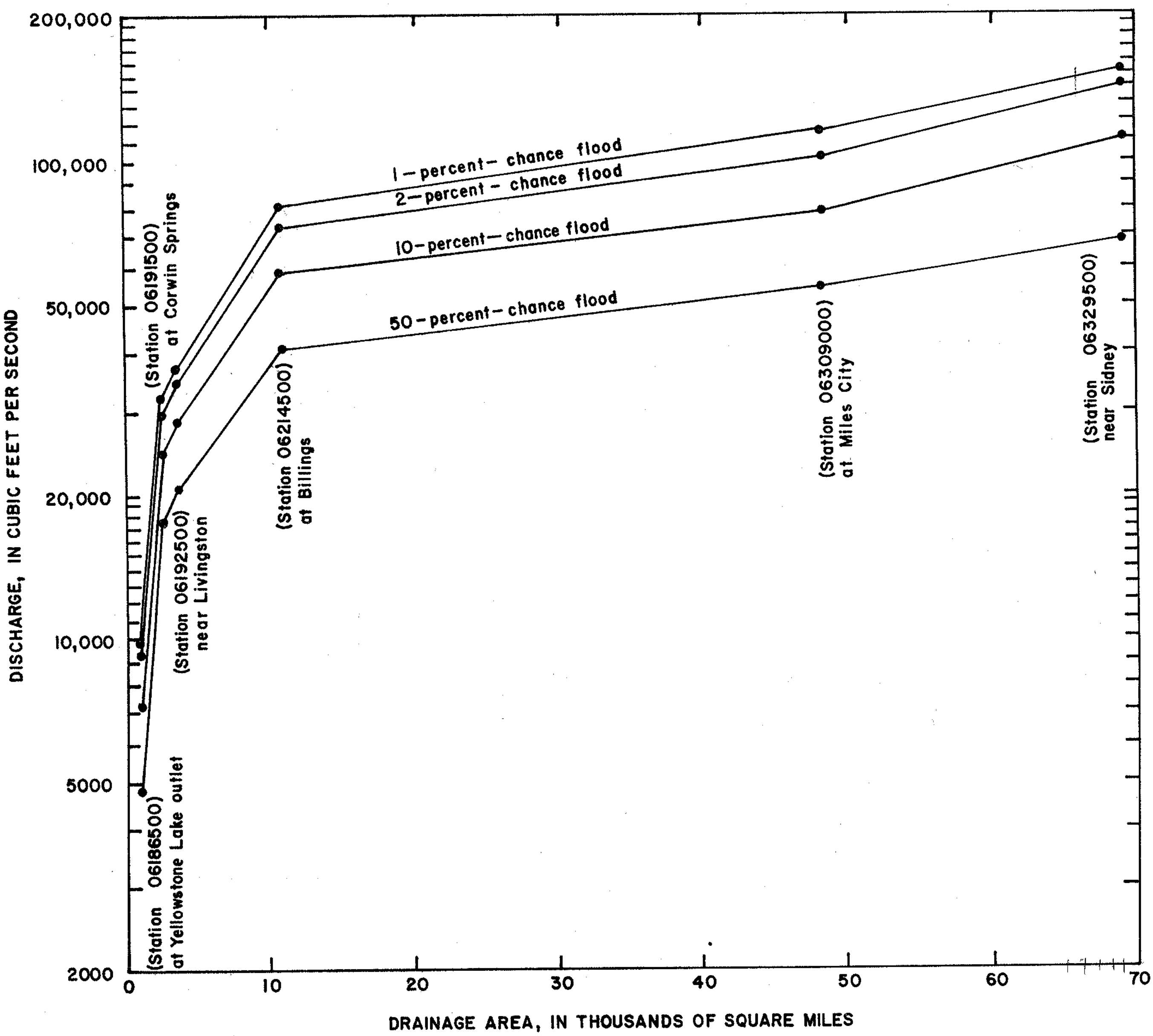


Figure 22.--Relation of discharge to drainage area for selected flood frequencies along the main stem of the Yellowstone River.

ILLUSTRATIVE EXAMPLES

The procedure for determining flood magnitude at ungaged sites is shown by the following examples:

Example 1. (Transferring data from gaged site)

Determine the flood magnitude for an exceedance probability of 1 percent (recurrence interval of 100 years) for Lake Creek at Troy, Montana, at an ungaged site where the drainage area is 140 square miles. From table 4 (West Region) the drainage area upstream from the gaging station (12303500) is 210 square miles and from table 4 the 1-percent flood is 5,000 cubic feet per second. From the equations for the West Region (table 1), the exponent on drainage area (A) for a 1-percent flood is 0.80. Using equation 3, the flood magnitude for a 1-percent exceedance probability at the site is:

$$Q_{1\%} = (140/210)^{0.80}(5{,}000)$$

$$= (0.723)(5{,}000)$$

$$= 3{,}620 \text{ cubic feet per second}$$

The ungaged drainage area (140 square miles) does not differ from the gaged drainage area (210 square miles) by more than 50 percent, so this relation probably will give reasonably accurate results.

Example 2. (Using the regression equation)

Determine the flood magnitude for an exceedance probability of 2 percent (recurrence interval of 50 years) for an ungaged site in the Southwest Region where the drainage area (A) is 10.1 square miles, the percentage of the total basin area above 6,000 feet sea-level datum (HE) is 85, and the basin mean geographical factor (G_f) from figure 6 is 1.0.

From the Southwest Region equations (table 1), the flood magnitude for a 2-percent exceedance probability is:

$$Q_{2\%} = 802\ A^{0.71}(HE+10)^{-0.68}G_f$$

$$= (802)(10.1)^{0.71}(95)^{-0.68}(1.0)$$

$$= (802)(5.16)(0.0452)(1.0)$$

$$= 187 \text{ cubic feet per second}$$

The site also was visited and the channel was found to be reasonably uniform and stable. The active-channel width was measured and was determined to be 6.5 feet.

From the Southwest Region equation (table 2), the flood magnitude for a 2-percent exceedance probability is:

$$Q_{2\%} = 240\ W_{AC}^{1.25}(HE+10)^{-0.59}$$

$$= (240)(6.5)^{1.25}(95)^{-0.59}$$

$$= (240)(10.4)(0.0681)$$

$$= 170 \text{ cubic feet per second}$$

Estimates of the flow are similar using either method and the standard error differs by only 1 percent, so an average of the two estimates could be used.

Example 3. (Using the regression equations when the drainage basin is in two regions)

Determine the flood magnitude for an exceedance probability of 2 percent (recurrence interval of 50 years) for a site in northeastern Montana where 10.5 square miles of the total drainage area is in the Northeast Plains region and 32.2 square miles of the total drainage area is in the East-Central Plains region. That part of the drainage basin in the Northeast Plains region has an average January minimum temperature (JANMIN) of -2 degrees Fahrenheit from figure 5, and a basin mean geographical factor from figure 6 of 1.2.

From the Northeast Plains Region equations, the flood magnitude for a 2-percent exceedance probability is:

$$Q_{2\%} = 492\ A^{0.54}(JANMIN+10)^{-0.39}G_f$$

$$= (492)(42.7)^{0.54}(8.0)^{-0.39}(1.2)$$

$$= (492)(7.59)(0.444)(1.2)$$

$$= 1{,}990 \text{ cubic feet per second}$$

That part of the drainage basin in the East-Central Plains has a precipitation intensity (I_{24-2}) from figure 4 of 1.8 inches and a basin mean geographical factor of 1.2 from figure 6. The flood magnitude for a 2-percent exceedance probability as determined from the East-Central Region equations is:

$$Q_{2\%} = 180\ A^{0.40}I_{24-2}^{2.28}G_f$$

$$= (180)(42.7)^{0.40}(1.8)^{2.28}(1.2)$$

$$= (180)(4.49)(3.82)(1.2)$$

$$= 3{,}700 \text{ cubic feet per second}$$

The weighted average flood magnitude for a 2-percent exceedance probability is:

$$Q_{2\%} = 1{,}990\left(\frac{10.5}{42.7}\right) + 3{,}700\left(\frac{32.2}{42.7}\right)$$

$$= 3{,}280 \text{ cubic feet per second}$$

CONCLUSIONS

Estimating equations relating annual flood magnitude and frequency to various basin characteristics were developed for eight hydrologic regions in Montana. In three of the regions, equations also were developed relating flood magnitudes to basin characteristics and channel-geometry measurements. Flood magnitudes can be estimated for exceedance probabilities of 50, 20, 10, 4, 2, and 1 percent for natural-flow streams. The maximum number of basin characteristics found to be significant in the regression equations in any region was four, including a geographical factor. The minimum number of basin characteristics included in any of the equations was three, including a geographical factor. Drainage area was the most significant basin characteristic in all regions.

Relations between channel-geometry measurements and maximum flows were found to be significant in three of the regions. Measurements of channel features were available for 265 of the 403 stations used in the analysis. The estimating equations that use channel geometry probably could be improved if measurements were available for all stations.

The standard error of estimate for equations that estimate floods with an exceedance probability of 1 percent ranged from 43 to 82 percent when using the geographical factor, and from 43 to 87 percent when not using the geographical factor. The standard error of estimate for equations that use channel-geometry and basin characteristics to estimate floods with an exceedance probability of 1 percent ranged from 39 to 75 percent. The standard errors of estimate for equations used to estimate floods for most of the exceedance probabilities were comparable to those of previous regression analysis by Parrett and Omang (1981).

However, the standard error of estimate is only one indicator of the reliability of the estimating equations and multiple regression was only one tool used in the analysis. Other factors also improved the regression results in this report over those in previous reports. Individual flood-frequency curves from log-Pearson type III analyses were improved because a longer period of record was available at each station. An updated skew analysis was used to develop the frequency curves. Also, new stations added to the data base have drainage areas closer in size to drainage areas used by planners and design engineers.

A technique also is presented for estimating flood magnitude and frequency for ungaged sites on gaged streams using a drainage-area ratio adjustment factor. Curves relating flood magnitude to drainage area were prepared for the major streams having several gaged sites.

REFERENCES CITED

Boner, F. C., and Buswell, G. W., 1970, A proposed streamflow data program for Montana: U.S. Geological Survey Open-File Report, 70-33, 96 p.

Boner, F. C., and Stermitz, Frank, 1967, Floods of June 1964 in northwestern Montana: U.S. Geological Survey Water-Supply Paper 1840-B, 242 p.

Dodge, E. R., 1972, Application [of] hydrologic and hydraulic research to culvert selection in Montana: Bozeman, Montana State University, 2 volumes, 118 p.

Johnson, M. V., and Omang, R. J., 1976, A method for estimating magnitude and frequency of floods in Montana: U.S. Geological Survey Open-File Report 75-650, 35 p.

Matthai, H. F., 1969, Floods of June 1965 in the South Platte River basin, Colorado: U.S. Geological Survey Water-Supply Paper 1850-B, 64 p.

National Weather Service, 1973, Precipitation-frequency atlas of the western United States, Volume 1 - Montana: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, 41 p.

Omang, R. J., Parrett, Charles, and Hull, J. A., 1983, Mean annual runoff and peak flow estimates based on channel geometry of streams in southeastern Montana: U.S. Geological Survey Water-Resources Investigations 82-4092, 41 p.

Parrett, Charles, and Omang, R. J., 1981, Revised techniques for estimating magnitude and frequency of floods in Montana: U.S. Geological Survey Open-File Report 81-917, 66 p.

Parrett, Charles, Omang, R. J., and Hull, J. A., 1983, Mean annual runoff and peak flow estimates based on channel geometry of streams in northeastern and western Montana: U.S. Geological Survey Water-Resources Investigations Report 83-4046, 53 p.

SAS Institute, Inc., 1979, SAS user's guide, 1979 edition: Raleigh, N.C., 494 p.

U.S. Army Corps of Engineers, 1958, Frequency of New England floods: Sacramento, Calif., Civil Works Investigations Project CW-151, Flood Volume Studies-West Coast, Research Note 1, 4 p.

______1969, Flood plain information, Flathead, Stillwater, and Whitefish Rivers, Kalispell-Columbia Falls, Montana: Seattle, Wash., Seattle District, 57 p.

______1973, Flood plain information, Great Falls, Montana, Volume 1, Sun River: Omaha, Nebr., Omaha District, 28 p.

U.S. Environmental Data Service, 1971, Climate of Montana: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Climatography of the United States No. 60-24, 21 p.

U.S. Soil Conservation Service, 1977, Average annual precipitation, Montana, based on 1941-1970 base period: Bozeman, Mont., 13 p.

U.S. Water Resources Council, 1981, Guidelines for determining flood flow frequency: Bulletin 17B, 27 p.